The Impact of Climate Change on the Future of Pacific Maritime Supply Chains, Seaports and Shipping: How stakeholders can adapt

by

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ABSTRACT

What will climate change really mean for a world increasingly dependent upon seaborne trade, globalisation and supply chains? How much will it cost? Do we retreat; adapt or surrender? For the Pacific, virtually all economic activity and development, key stakeholders and physical survival are vulnerable to this increasingly significant risk affecting the continuance and future of seaports, shipping, coastal ecosystems and communities. This study aims to achieve insights into resolving climate change uncertainty for maritime supply chains and stakeholders. It considers three key questions, the first being to identify the current and projected future disruption risks for Pacific Island maritime supply chains from the consequences of climate change. Secondly it assesses the economic impacts of these risks, and thirdly it proposes how key supply chain stakeholders can adapt to minimise the economic impacts.

This study's research methodology identifies and evaluates projected risks, impact costs, constraints to adaptation and adaptation solutions for both individual maritime supply chain (MSC) stages and across an entire supply chain system. It proposes an original multi-stage synthesised research methodology combining these factors through field research case studies using both qualitative and quantitative methods combining direct stakeholder consultation, risk and vulnerability assessments and an impact cost analysis model. It recommends an empirical risk and impact cost data approach. It provides a Pacific MSC study via the Cook Islands as its specific empirical contribution; validating this method and the need to prioritise climateproofing adaptation strategies.

The key findings showed the significance of stakeholder risk perceptions as influencing the extent of awareness, impact costs experienced and adaptation. Qualitative content analysis found local stakeholders perceived themselves well aware of climate change awareness, impacts and solutions They identified the significance of effective information, legislation, psychology, access to funding and investing in eco-capital as imperative for transforming risks into climateproofed opportunities. Triangulation of results provided the first complete, time-series data for risk events for the Cook Islands from 1900-2015. The study estimated future climate change as costing approximately a minimum of $139 billion.

The study's key contribution is better awareness of the vulnerability, challenges, and understanding of climate change impact and adaptation solutions for MSCs; (especially in the Pacific region) to help informed decision-making and choices. It offers a commercial, supply chain stakeholder requirement and ecological capital perspective as its academic theoretical contribution. The potential policy and theory implications of these findings are that existing stakeholder uncertainty towards climate change's consequences for individual supply chain stages can be further reduced. This futureproofs resilience more effectively across different scenarios, time horizons, multiple risks, impact costs and constraints. This aims to reduce the uncertainty and significant opportunity and externality costs; disruptive climate change presents for 'business as usual' expectations.

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LIST OF ACRONYMS

ADB:	Asian Development Bank
AOSIS:	Alliance of Small Island States
AusAID:	Australian Agency for International Development
˚C:	Degrees Celsius
CBA:	Cost Benefit Analysis
CM:	Centimetre
CO_2:	Carbon Dioxide
CSIRO:	Commonwealth Scientific and Industrial Research Organisation
DWT:	Deadweight Tonnes
EEZ:	Exclusive Economic Zones
EIA:	Environmental Impact Assessment
ENSO:	El Nino Southern Oscillation
FSM:	Federated States of Micronesia
GCM:	General Circulation/Global Climate Model
GDP:	Gross Domestic Product.
GEF:	Global Environmental Facility
GFDRR:	Global Facility for Disaster Reduction and Recovery
GIS:	Geographic Information System
FAO:	Food and Agricultural Organisation
IAPH:	International Association of Ports and Harbours
IMO:	International Maritime Organisation
IPCC:	Intergovernmental Panel on Climate Change
ITCZ:	Inter-Tropical Convergence Zone
JNAPs:	Joint National Action Plans
Km:	Kilometre
Km^2:	Kilometre squared
LDC's:	Less Developed Countries
L:	Litre/s.
MARPOL:	International Convention on Prevention of Pollution from Ships
M:	Metre

MM:	Millimetres
MP:	Members of Parliament
MPH:	Miles Per Hour
MSC:	Maritime Supply Chain.
NA:	Not Applicable/Available
NGO:	Nongovernmental Organisation
NOAA:	National Oceanic and Atmospheric Administration (USA)
PCRAFI:	Pacific Catastrophe Risk Assessment and Financing Initiative
PIC's:	Pacific Island Countries
PICCAP:	Pacific Islands Climate Change and Adaptation Project
PIFACC:	Pacific Islands Framework for Action to Climate Change
PPM:	Parts per million
PREP:	Pacific Resilience Programme (World Bank)
RCM:	Regional Climate Model
RMI:	Republic of Marshall Islands
SIDS:	Small Island Developing States
SLR:	Sea Level Rise
SOPAC:	Pacific Islands Applied Geoscience Commission
SPC:	Secretariat of the Pacific Community
SPCZ:	South Pacific Convergence Zone
SPREP:	South Pacific Regional Environmental Program
SST:	Sea Surface Temperature
TEU:	Twenty Foot Equivalent Unit
UN:	United Nations
UNCLOS:	United Nations Convention on the Law of the Sea
UNCTAD:	United Nations Conference on Trade and Development
UNDP:	United Nations Development Programme
UNESCAP:	United Nations Economic and Social Commission for Asia and the Pacific
UNFCCC:	United Nations Framework Convention on Climate Change
UNISDR:	United Nations Office for Disaster Risk Reduction

USP:	University of the South Pacific
WRF-ARW:	Advanced Research Weather Research and Forecasting Model
WMO:	World Meteorological Organisation
WTO:	World Trade Organisation

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CHAPTER 1: INTRODUCTION

1.1 RESEARCH BACKGROUND

Throughout history humanity has initiated many changes, migrating to every part of the planet, with many advances, achievements and failures. However, of all challenges currently presenting, the most imperative risk humanity all face as one population and interconnected global ecosystem is climate change. Whether global, regional, local, collective or individual, climate change is increasingly established as the factor that most directly threatens human achievement. Despite the uncertainty of its actual disruption impact, global climate change is predicted by the Intergovernmental Panel on Climate Change (IPCC 2015) to provide a continuously sustained threat to the health, welfare and survival of all organisms. It is forecast to rapidly accelerate from increased human pressures of unsustainable economic development, resource exploitation, pollution and population growth.

According to the majority of established sources such as Thomas, Albert and Perez (2013) and Bojinski *et al.* (2014), considerable scientific uncertainty remains over the actual disruption impact of climate change, its challenges and solutions. From these sources, disruption for this thesis refers to climate change's potential risks, costs and consequences. Risks refer to the repeated probability, possibility or likelihood of an event occurrence. Humanity's actions are disrupting Earth's natural ecosystem and climate process with potentially fatal consequences. This is commonly accepted by international organisations including the United Nations (2010), officially by many governments, relevant academics, religions, nongovernmental organisations and communities (especially through membership and support of the following organisations). As climate change's physical impact increases over time, this thesis agrees with organisations including the International Association of Ports and Harbours (IAPH) (2010), the United Nations (2010), the Pacific Island Forum (2013), the Secretariat of the Pacific Community (SPC) (2014), the International Maritime Organisation, the IPCC (2015), and many other industry stakeholder representative associations. They consider it essential to understand and prioritise climate change. It is also necessary to resolve, mitigate and adapt to its uncertain costs, risks and consequences, which challenge continued survival, prosperity, development and progress. Globally, the following consequences are commonly used as assumptions for research scenarios. These are predicted by the joint IPCC in its latest report, by Kunreuther *et al.* (2014) These consequences will be accepted as direct threats to maritime supply chains (MSCs) for the purposes outlined in this thesis; through the following points:

- An increase of 1.5-2º Celsius in global average surface, atmosphere and sea level temperature levels based on historic inventory levels; even if emissions were to cease.
- An increase of 2.5-4ºC if emissions are stabilised at the current, medium growth rate by 2100.
- Increases of 4-7ºC if emissions are not reduced.
- A 0.5 metre global, average sea level rise (SLR) is projected for a low risk, current growth scenario, where emissions are highly reduced. A 1.0m rise exists for a medium risk (if emissions are stabilised). Up to 2m exists for a high risk, continued emissions increase scenario by 2100 if current, global GDP growth rates of 3-5% annually remain.
- Greenhouse CO_2 emissions would have to stabilise around 430-450 parts per million (ppm) at present. It could reach no higher than 550 ppm (530–580) by 2100 to ensure survival conditions.
- A projected increase in the frequency, duration and intensity of climate-change related natural disasters, including storms, flooding, tsunamis, hurricanes, typhoons, heatwaves and landslides.

Despite the uncertainty of capacity for human existence on other planets, an unwillingness to consider global climate change as the most significant threat is causing our planet to lose its natural ecological capacity to resist. Based on IPCC (2015) updated estimates, greenhouse gas emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3) increase. Gases continue to accelerate swiftly across nations, contributing to global climate change. These threaten the absorptive capacity of Earth's oceans, mangroves, wetlands, forests, coral reefs, integrated coastal ecosystems and other ecological resilience barriers or pollution sequestration sinks. A United Nations Office for Disaster Risk Reduction (UNISDR) 2015 report estimated the human species now exists on natural capital – unsustainable existing finite resources. It has exceeded our ecological footprint, surpassing Earth's capacity to regenerate by over 50%. Global climate change costs are also becoming more apparent and immediate through the accelerated frequency of related disaster risks.

Actions have consequences. The neglect of Earth's planetary ecosystem also has consequences. The assumptions above predict dramatic, anthropogenically-enhanced, climate change consequences. These affirm industries and sectors cannot afford complacency and inertia in prioritising and adapting to such risks. According to the United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP 2015), the world economy lost over $2.8 trillion between 1970 and 2014 through climate-related natural disasters in direct physical infrastructure damage. Each year is expected to cost a minimum of $250-300 billion (UNESCAP 2015) in further direct economic infrastructure damage, without additional climate-related disruption or adaptation costs. The Asian Development Bank Institute and Asian Development Bank (ADB 2013) estimated the Asia-Pacific region alone experienced over $60 billion in direct economic loss during 2001-2011. The costs of maladaptation, delay and apathy could threaten the survival prospects of most vulnerable coastlines and settlements. It could submerge entire nations, especially small island states from the Caribbean and Maldives to the Pacific (Lorde 2013). Preliminary research i.e. the South Pacific Regional Environmental Programme (SPREP) (2011), International Climate Change Adaptation Initiative (2013) and IPCC (2014), anticipates a projected increase in the intensity, frequency, spatial location, duration and disruption cost consequences of climate-related events. This is increasingly probable if all affected sectors continue to ignore the greatest risk of this age and global economy. It is more certain if they contribute to global warming at the current unsustainable rate. It is necessary to consider how to restore Earth's ecological resilience capacity. Stakeholders need to know how to react and ultimately adapt to the actual threat of climate change

According to reports e.g. Allison *et al.* (2009) and Ramsay (2013), direct climate change consequences threaten ecosystems, human population, society, cultural heritage, health, sanitation and economies. Consequences include projected property and coastal infrastructure damage, disruptions to trade, transport, agriculture, tourism, industry and utilities. Certain adverse environmental impacts include collapsing ecosystems from direct damage to species numbers, habitats, food sources, biodiversity and geographic distribution, coral reef bleaching, deforestation and soil erosion. Lorde *et al.* (2013) estimated that over 3,900 km of Caribbean land would be inundated by 2050. This creates direct coastal economic damage of over $798.7 billion, if current economic activity does not become more environmentally sustainable. Collapsing coral reefs and associated ecosystems, from offering 88% of environmental damage absorption capacity in 2005 to under 20% by 2050 (Lorde *et al.* 2013), further indicate the consequential losses of reducing existing protection. Aside from potential direct property damage, increased beach erosion, coral reef bleaching and biodiversity loss, along with higher frequencies of storms and other related events, are forecast to reduce natural and aesthetic values. It lowers the gains of economic activity and tax revenue from tourism for the highly vulnerable, global coastal sector.

Climate change is expected to increase death, injury and other public health risks. It could promote the spread of malaria, dengue fever and typhus from changes in species-borne diseases and potential damage threats to public water and sanitation systems (UNESCAP 2015). Other climate change impacts include potential threats to human safety and stability, e.g. displaced populations and coastal asset damage from increased flooding, drought, precipitation, temperature, humidity and wind velocity (Hay 2011). Adverse economic impacts include damages to road, rail, airport and seaport transport network connections. It includes damage to utilities e.g. water, electricity and waste disposal. These influence the functioning capacity of other economic sectors and most essential human services from healthcare to education, transport, shelter and food production (ADB Institute and ADB 2013).

Other economic climate change impacts include changes in geographical distribution, potential damage to agriculture and aquaculture quality, industrial production delays and output quantities. This influences prices, cargo throughput, economic demand and supply. Agriculture and aquaculture variations also affect social and political stability, including potential food security directly, crime rates and migration levels indirectly (International Climate Change Adaptation Initiative 2013). These have further adverse, economic impacts on local and international trade. This reduces potential imports and exports, unemployment, labour productivity, foreign revenue and overall balance of payments including related tax revenue (United Nations Conference on Trade and Development UNCTAD 2014).

There is a direct interaction between climate change and maritime supply chains. According to UNCTAD (2014) over 90% of the world's trade is seaborne, based on global macroeconomic contributions and connections of seaports, vessels, maritime economic hinterlands and their interconnecting supply chains. Globalisation relies on continuing and facilitated trade. However, prospects for the global future of shipping and seaports have never seemed so uncertain. Its participants seldom consider what happens when those connections face disruption risks and potential challenges, threatening commercial viability and physical survival. Maritime supply chains (MSCs) throughout the world face significant commercial challenges from the 2008 global financial crisis's aftermath. Contracted economic activity exists from a lack of stakeholder demand, an oversupply of vessels, the increasing size and cargo capacity of these vessels and seaport capacity. This derived from significant investments in port expansions increasing inter-port competition (Dyer 2013; UNCTAD 2014). Other lingering challenges include increases in regulatory and insurance expenses, reduced banking finance access and additional legal, environmental, commercial, political, social and physical risks (UNCTAD 2014). However, supply chain survival prospects are increasingly threatened by encroaching sea levels, higher temperatures, wind velocity and precipitation. Increased frequencies and intensities of hurricanes, tsunamis, droughts and other climate-related influences (IPCC 2015), adversely disrupt port, shipping and overall MSC performance. This has been vividly illustrated by 2005 Hurricane Katrina in New Orleans, 2012 Superstorm Sandy in New York, the October 2017 storm causing a ship to blockade Durban harbour and displace cargoes of nurdles as far as St Helena, and Hurricane Ivan's $4.42 billion damage from 270 kph winds to the Greater Antilles in 2004.

One related theoretical gap is identified consistently from assessing academic research e.g. Regmi and Hanaoka (2009), Knapp, Bordeau and Falco (2011), Becker *et al.* (2013) and Kong *et al.* (2013) for ports only. This identifies how comparatively little is known about potential, climate change impacts on MSCs. Even general technical planning reports, concentrating on projected risks for international logistics networks for stakeholders (UN Economic Commission for Europe 2014) and ports (Port of San Diego 2013), ignore the entire supply chain. Currently these risks impose significant yet understated, under-investigated costs, risks, concerns and consequences for dependent stakeholders. Indirectly, the sustainability of entire economies and ecosystems are also threatened, although not specifically investigated in this study. According to established reports e.g. Samples, Riseng and Diana (2014), few port authorities, shipping companies and stakeholders (including communities) seek answers for themselves about these direct effects. Few investigate the phenomena, possible consequences, costs or potential investments and whether, when and how they will need to adapt.

This thesis seeks to detail impact costs through a specific Pacific case study. This seeks to ascertain existing climate change awareness and the extent to which these stakeholders are prioritising adaptation resilience strategies. This is especially significant for all affected stakeholders, who (directly or indirectly) depend on supply chains to continuously function efficiently, with minimal disruption risk. These same stakeholders, via research by Allison *et al.* (2009) and others, are increasingly advised to consider what even a modest rise in sea level from glacial melt and thermal, ocean expansion might mean. Significant implications arise for coastal communities – to homes, infrastructure, tourism, fisheries, businesses, transport and the ecosystem. Even if these stakeholders live inland and are wealthy enough to resist like Switzerland and Austria, these stakeholders are unlikely to be exempt from potential, climate change consequences globally. This extends to mass migration for those fleeing to survive. Submergence of entire coastlines or nations (SPREP 2011), affects all.

1.2: RATIONALE FOR THIS STUDY

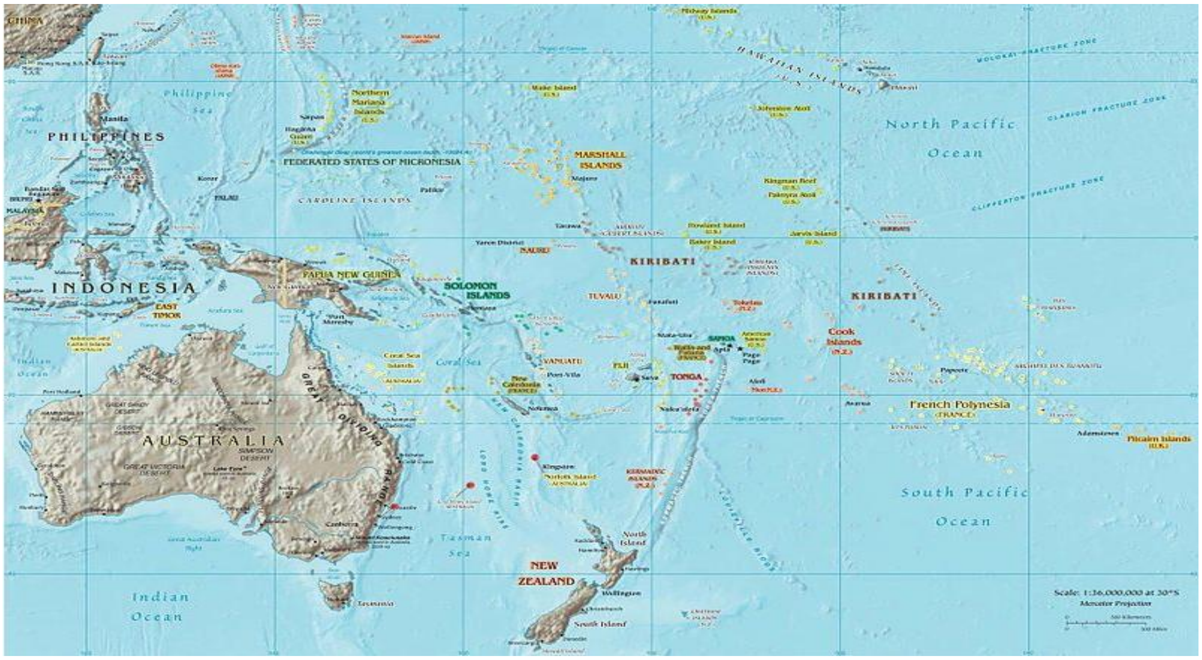
A shortage of research focus on the impact of climate change on maritime supply chains provides the impetus for this study. It is among the emergent pioneers including Mitsakis *et al.* (2013) and Karambas (2015), particularly concentrating on this key research problem. It focuses on climate change's economic and physical impact costs on MSCs from producer to consumer (as defined in Chapter 2). It seeks to enhance practical understanding of IPCC, theoretical predictions. It acknowledges other contributing threats beyond CO_2 emissions alone, which many sources including Tran (2013) solely concentrate upon. Other risks include pollution, collapsing ecological resilience and high population growth rates for scarce resources. This thesis specifically concentrates on two risks. Global gradual and sudden risks primarily present disruption to all individual, community and MSC stakeholders. This is based on current inconsistent and asymmetrical information over projected costs, risks and consequences, from Knutti, Abramowitz and Collins (2010) to Lam and Su (2015). These limit direct understanding of climate change's direct and indirect impact plus effective and coordinated adaptation responses. For all the extensive previous research e.g. Becker and Caldwell (2015) and McLaughlin, Murrell and Des Roches (2011), uncertainty exists over defining climate change, resilience, risks and adaptation strategies and potential consequences. Papers such as Hallegatte *et al.* (2010) and Cooper and Pile (2014) often pursue myriad, diverse research methodologies. A consistent academic approach to understanding climate change across MSCs does not exist, complicating any effective solutions to this ultimate risk.

Further rationale includes the need to answer if it is possible to identify, value and predict the uncertain consequences of gradual and sudden risks on MSCs to assist stakeholders. Gradual examples include local, regional and global sea level, wind, precipitation, current and temperature rises, changes in currents, coastal erosion, sedimentation and wave energy. These risks are expected to occur over a longer time period with lesser financial, uncertainty, time, opportunity, congestion, reputational, resource and other opportunity impact costs for MSCs. Risks contrast with the sudden impact of natural disasters (Kong *et al.* 2013; McEvoy *et al.* 2013; Scott *et al.* 2013). Climate change also has both direct and indirect effects, not easily quantifiable and measurable, which previous research including Inner City Fund International (2008) has failed to establish a consensus upon. This thesis further seeks to understand central risks to improve upon contemporary research sources.

The rationale for focussing on the Pacific area derives from its increased vulnerability to climate change. Climate-change-related events influence MSCs directly from production to consumption with reduced revenue, delayed cargo throughput and increased risk exposure/impact costs. The threat is more evident for more vulnerable nations/areas including the Pacific. For example, the Solomon Islands floods (SPREP 2014) demolished natural ecosystem, climate protection barriers such as mangroves and dunes. Floods cost over $55 million in taro crop production, residential property and infrastructure damage alone. A more recent example occurred with Cyclone Pam’s storm surge on Vanuatu on 13th March 2015. Its 300 km/h winds devastated over 48,000 homes leaving 100,000 homeless and 24 deaths (Flannery and Steffen 2015), with unascertained high economic and other opportunity costs. These two are among the latest in a history of increasingly severe disasters, in one of the world’s most highly geographically, economically and socially exposed regions.

As Figure 1.1 illustrates, the Pacific region consists of over 155,557,000km^2 of ocean territory (8,497,017 for sovereign nation, land area). It is home to an estimated 38,039,400 people, directly affected by any climate change consequence. The region is defined by sources such as UNESCAP (2015) and University of South Pacific (2013) to include sixteen sovereign nations. Nations include Australia, Cook Islands, Fiji, Kiribati, Marshall Islands, Federated States of Micronesia, Nauru, New Zealand, Palau, Papua New Guinea, Samoa, Solomon Islands, Tonga, Tuvalu and Vanuatu. Affected islands and dependent territories include American Samoa, French Polynesia, Guam, New Caledonia, Tokelau and the Wallis and Futuna Islands. The figure also illustrates the significant land and ocean surface area affected. These vulnerable areas (Australia, Papua New Guinea and New Zealand aside), mostly consist of small, lower-lying, island developing states that are physically exposed. They possess high population densities exceeding their ecological limit, with few resources and limited economic, institutional, and other capacities to resist.

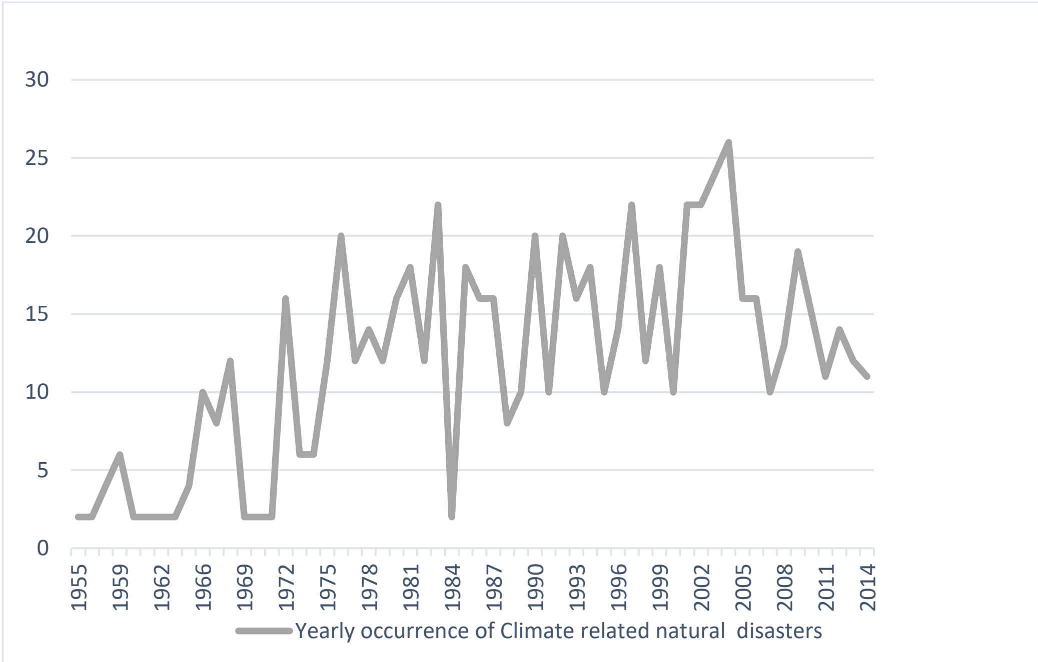
Figure 1.1: Pacific Region Overview.



Source: Wikipedia 2015.

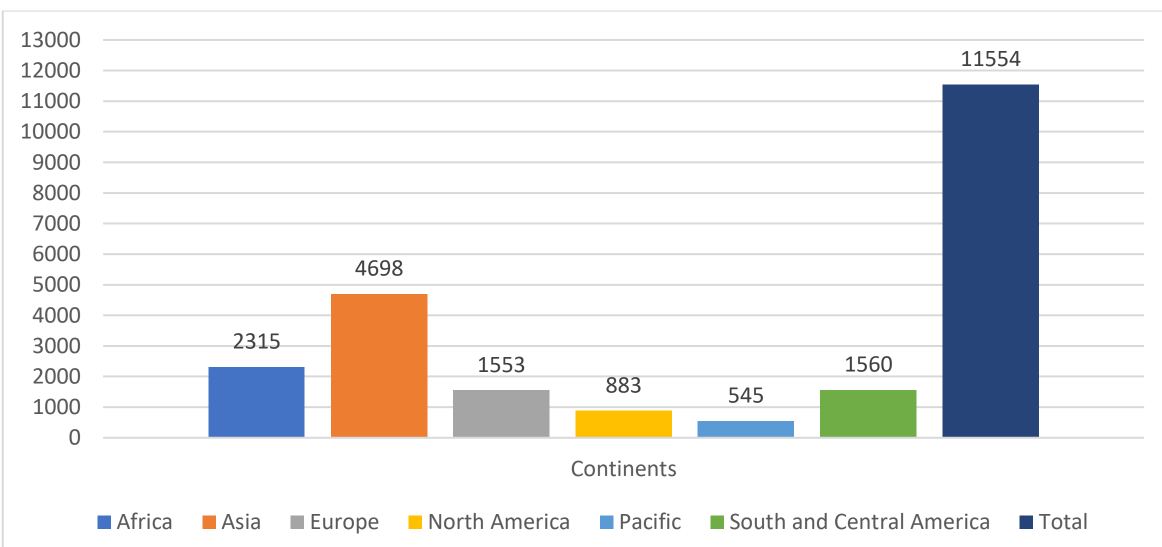
Anderson (2012), along with Guha-Sapir, Below and Hoyois (2015) in Figure 1.2, show increasing frequencies and intensities of climate disruption risks. Related disasters for the Pacific soared from an average of 2-4 disasters in the 1950's to 12-25 in the 2000's. As Figure 1.2 indicates, this indicates a significant increase over time. This further establishes the need to prioritise climate change, especially in the more risk exposed MSC sector. According to Kim *et al.* (2015) and Guha-Sapir, Below and Hoyois, (2015) in Figure 1.3, the Pacific and Oceania experienced an estimated 545 climate-related disasters between 1970-2014. These sources exclude bushfires, volcanoes, and earthquakes, uncertain to occur specifically as a consequence of climate change. Although the number of Pacific disaster risks appears historically fewer than other global regions, the actual impact cost is judged far more significant by SPREP (2012), SPC (2013), UNCTAD (2014), UNISDR (2015) and UNESCAP (2015). This derives from far fewer Pacific nations and territories existing, occupying a far smaller proportion of global population and total land area. However, climate change possesses a direct threat for resources, which provide a significant contribution to exports and percentage of GDP. It challenges immediate physical survival.

Figure 1.2: Overview of Event Frequency of Pacific Region, Climate Related Natural Disasters: 1970-2014.



Source: Adapted from Guha-Sapir, Below and Hoyois 2015.

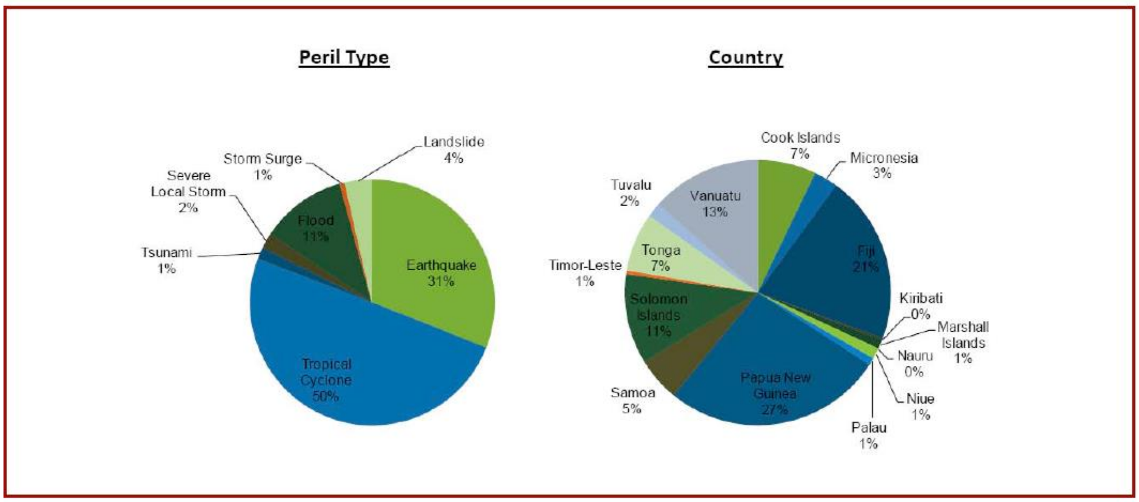
Figure 1.3: Total Occurrences of Global Climate Change Related Natural Disasters 1970-2014.



Source: Adapted from Guha-Sapir, Below and Hoyois (2015) estimates.

A significant climate change threat therefore exists for the Pacific region, where the intensity and frequency of these risks and damage is expected to increase, especially for MSCs and overall economies. In 2014 tropical cyclones composed 50% of all risks. 11% were floods and 3% were storms (Figure 1.4). However, earthquakes (31%) were not found by Guha-Sapir, Below and Hoyois (2015) as directly linked to climate change. The sample excluded Australia and New Zealand as developed nations with access to higher resources and higher informational and disaster-resilience capacity. Certain Pacific nations were more affected than others, with Papua New Guinea suffering 27% of regional disasters in 2014. Fiji experienced 21%, Vanuatu 13% and the Solomon Islands 11%. Geographically not just Pacific ports but the majority of world ports are vulnerable (Becker, Satoshi and Fischer 2011).

Figure 1.4: Pacific Region 2014, Climate Change Related Disruption Risk Type and Country



Source: PCARFI 2015, p.54.

The prime challenge facing these Pacific Island MSCs is their geographical isolation from neighbouring countries and central world shipping routes. They are even more dependent upon their seaports and maritime resources for economic growth, sustainable development and ultimate survival. According to Becker and Caldwell (2015) few communities, port authorities, governments and MSC stakeholders appear to realise the global economy's existing vulnerability to these hazards. This thesis is motivated to identify/assert this vulnerability exists and reduce the uncertainty of supply chain stakeholders in research such as Knapp, Bordeau, and Falco (2011). These frequently cite asymmetrical information over impacts as a significant constraint to prioritising and implementing climate change adaptation.

1.3: KEY RESEARCH QUESTIONS AND ULTIMATE OBJECTIVES

This thesis will focus on risks for certain commodities; affecting a significant proportion of their cargo throughput and shipping/port activity. This extends through all Pacific supply chain stages from producers to consumers. This study seeks to achieve the following research objectives

- To develop a theoretical framework to evaluate potential risks and impact cost consequences of climate change upon Pacific MSCs.
- To apply the analytical framework approach to analyse potential risks and economic impact costs of specific commodities' supply chains in individual Pacific countries. The analysis is conducted through field research case studies using both qualitative and quantitative methods combining direct stakeholder consultation, a risk-vulnerability assessment and impact cost analysis model.
- To propose and identify various adaptation solutions stakeholders can implement. These derive from identifying theoretical and practical departure points from previous research. This is crucial particularly for those facing similar constraints, uncertainty, risks and challenges to these Pacific nations and dependent territories. Given the above research objectives; this study seeks to answer the following key research questions (KRQ) and auxiliary related research questions (ARQ) below:

KRQA: What are the current and projected risks for Pacific Island MSCs from climate change consequences?

KRQB: What are the economic impacts of climate change risks on the future of Pacific Island MSCs and for a specific commodity?

Another significant problem is that most existing port infrastructure and services, shipping and supply chains have not adapted enough to endure the effects of even modest changes in climate event duration and intensity. Therefore, the following KRQC and two related questions (ARQI and ARQII), focus on how stakeholders can adapt to minimise these risks and survive.

KRQC: How can key supply chain stakeholders adapt to minimise the impact of climate change on Pacific Island MSCs?

> **ARQI: What are possible climate change adaptation solutions for Pacific MSCs?**
>
> **ARQII: What are the specific constraints/barriers to developing adaptation strategies for climate change?**

1.4 SIGNIFICANCE OF THIS THESIS

Considering just how much of the global population and globalisation depends on the future prospect and continuance of international MSCs, the problems presented by climate change to MSCs cannot be ignored, dismissed or trivialised. They directly and indirectly contribute a significant part of Pacific and global, present and future economic activity, primarily through ports and shipping. Ignoring the problem is anticipated to make the consequences much more expensive to resolve in the future according to Becker *et al.* (2013) and Gray *et al.* (2014). Maritime industry projects, especially the growth of port expansions and modernisation developments will become increasingly unsustainable, not just within this study's Pacific location but throughout the Southern Hemisphere and globally. The average port life expectancy without significant physical expansion ranges from 50-100 years on average (according to the International Association of Ports and Harbours (Anderson 2009). The Pacific region, exposed to so many risks, threatens this.

Through evaluating pertinent research sources (e.g. Anderson 2009), this thesis agrees that long-term solutions urgently need to be devised. However, increasing port, vessel and supply chain resilience, and ability to adapt to changing circumstances by investing in additional capacity/infrastructure, is complicated without knowledge of changing technological progress and climate uncertainty (Mazira 2010). Examples include its timescale, intensity, frequency, costs, benefits and other consequences as Allison *et al.* (2009) and Hearn (2012) analyzed. This thesis is significant for several reasons, especially to address increasing global concern over uncertainty around anthropogenically engineered, climate change disruption regionally and individually. It aims to provide additional insight towards risks and economic impact costs on Pacific islands' supply chains, as countries most vulnerable to climate change. This is achieved by answering research questions stated in section 1.3. This further helps to enhance understanding of what climate change will mean to those countries and MSCs most exposed, in a region historically known for being particularly susceptible with high disruption costs (UNISDR 2015). Predicted SLR can prompt the complete disappearance of nations such as Kiribati, Tuvalu, Nauru and Niue just a few metres above sea level. Other examples emphasise other regions but do not concentrate on this thesis's specific focus of Pacific MSCs, (i.e. Dasgupta *et al.* 2009 plus Regmi and Hanaoka 2009 for developing countries).

Although a growth in related global actions prioritising climate change exists in the last few decades, increasing public awareness, organisations and funding, significant research scholarship remains necessary, as it has not been previously interlinked in a theoretical framework for MSCs. This is imperative to reduce climate change uncertainty, especially as it affects the maritime economy and global supply chain, including seaports as catalysts of international trade. In contrast to previous studies e.g. Gurning (2011), this research advocates not only identifying theoretical indicators from reviewing academic sources, but also examines potential climate change impacts. The study findings are expected to develop a set of coordination and adaptation strategies these stakeholders can endorse to mitigate economic effects. In contrast to literature e.g. Petzold and Ratter (2015) it aims to utilise the perspectives of those stakeholders most experienced and qualified.

Ultimately this thesis follows previous, contemporary research efforts including Pacific Islands Forum Secretariat (2013) and PCARFI (2015) in identifying global and regional climate change consequences for these MSCs. It will contribute towards assessing the extent to which affected stakeholders are aware of the potential implications of climate change costs, benefits and risks. It aims to work towards the continued existence of this globally pivotal, economic region through further informational awareness. This adapts maritime infrastructure, services, port functions and vessels to risks, to survive at minimal disturbance and externality cost. It is necessary when considering the risks and opportunities climate change may initiate from the loss of entire Pacific islands, culture and nations, primarily due to developed nation emissions (IPCC 2015). Previous research and technical port development, feasibility reports are mostly First World orientated, e.g. Chhetri *et al.* (2015) for Port Kembla, Australia. These neglect information, consequences and solutions for specific developing and island nations. This research is further motivated from a Pacific and primarily developing world case study viewpoint, to provide greater insight into specific developing country challenges and considerations, methodology approaches and key stakeholder requirements. Australia and New Zealand are included in statistics and information sources, as they present a developed world approach to climate change adaptation. They are similarly fundamentally affected as part of the Pacific regional climate, ecosystem and economy and main sources of development financing. For developing countries facing financial, environmental and other opportunity costs of finite resources, this thesis has further advantages. It works towards ensuring the most efficacious utilisation of supply chains and survival adaptation solutions; rather than superfluous, expensive investments they cannot afford. It has the further advantage of not only utilising literature but also practical case studies. These can be utilised towards a more consistent, climate change impact evaluation and adaptation, research methodology.

Globally dependent stakeholders and communities are under-prepared to adapt to anticipated disruption. Becker and Caldwell (2015) contend this through providing a survey testing port stakeholder, climate change awareness. The two developed countries in the region, Australia and New Zealand; are predicted to have greater pressures to aid other Pacific Islands who have less ability to adapt or mitigate. This thesis especially aims to emphasise the risks and concerns of ultimate survival for Pacific MSCs. These are geographically remote and economically, ecologically, socially, culturally and politically marginal/peripheral. It re-iterates that humanity needs the Pacific. Its example can provide many solutions towards further reducing the uncertain fate facing ecosystems, communities, economies and trade from past, present and future climate change.

1.5 SYNOPSIS OF THESIS STRUCTURE

The thesis is structured into eight chapters along with appendices.

Chapter 2 establishes the thesis's theoretical framework in a Literature Review of established and contemporary research sources. It attempts to provide greater clarity into the strengths and weaknesses of similar previous research undertaken related to climate change impact studies. This identifies existing literature gaps to justify the methodology used in Chapters 3 onwards. To identify the impact of climate change upon Pacific MSCs, it defines key concepts of climate change, risk, vulnerability and MSCs (sections 2.2-2.4). Section 2.5 identifies climate change disruption risks, impact costs and adaptation strategies on ports, shipping and the subsequent entire supply chain. This is established by literature to address KRQA, KRQB and KRQC, affecting these stakeholder requirements. This establishes a theoretical motivation for this thesis, to understand the uncertain potential future for a climate change affected series of Pacific supply chains. It represents a significant improvement or departure point from existing research, in formulating an integrated research methodology (section 2.7) and adaptation solution (section 2.6.5) for supply chain stakeholders.

Chapter 3 proposes an integrated, mixed method includes risk and vulnerability analyses of each Pacific MSC example in stage II (KRQA). This is combined with an economic impact cost analysis for climate change in Stage III (KRQB). Adaptation solutions are linked in Stage IV (KRQC). The chapter will describe the Stage I sample, recruitment strategy, research questions, data collection and data analysis methods. It outlines model assumptions and limitations, data management policy guidelines and ethical considerations. This thesis proposes climate change costs on each supply chain stage, stakeholder and Pacific location for a specific commodity can only be resolved through comprehending and synthesising various risk projections in Chapter 4. This addresses KRQA by outlining future global, Pacific regional and individual country, risks, scenarios and assumptions. Identifying risks addresses the key constraint of asymmetrical information over projected climate change uncertainty, via enhancing awareness, resilience and adaptation. Risks also affect the projected frequency, intensity and duration of impact costs and the extent to which stakeholders need to prioritise adaptation (KRQB and KRQC). This chapter summarises relevant international legislation and existing global legal responses to this greatest of future maritime challenges.

Chapters 5 to 7 provide results to test empirically the integrated, theoretical framework developed in Chapter 3, for the Cook Islands MSC case study. Chapter 5 introduces the country, its MSC, seaports and affected area for a single vulnerable commodity for each selected example. Specific risk types and probabilities will be ascertained and summarised prior to establishing a vulnerability-risk assessment for key MSC stages. This considers how Pacific supply chains will be significantly adversely affected (KRQA). Chapter 6 (Stage 2) empirically calculates an economic impact cost analysis from historic data for projected risks under climate change scenarios (KRQB). Chapter 7 assesses and recommends existing and proposed adaptation strategies. It identifies site specific, adaptation constraints for Pacific MSC stakeholders. Chapter 8 summarises the conclusions, evaluating the extent to which the KRQ's and ultimate objectives have been addressed. The intended purpose directs this thesis towards a greater theoretical and practical insight into the most significant global risk of climate change, which threatens the continued existence of the Pacific, its sovereign members and MSCs, specifically through the direct impact on ports and shipping. Each chapter strives towards a greater practical and theoretical pathway to adaptation and survival for stakeholders. These are aimed at improving the probability of survival and lowering associated externality, disruption and opportunity costs. It pinpoints certain research limitations and possible directions for future research.

CHAPTER 2 LITERATURE REVIEW: CLIMATE CHANGE DEFINITIONS AND IMPACTS ON MARITIME SUPPLY CHAINS.

2.1: INTRODUCTION

Structurally, this literature review has been divided into several theoretical areas. This approach is supported by UTAS theses (Fei 2009; Gurning 2011; Sakalyn 2014; Pateman 2015). It considers an issues-based approach, providing the advantage of a more focused, pertinent and consistently systematic appraisal. It pinpoints potential and actual theoretical issues relating to climate change for the future commercial survival of maritime supply chains (MSCs) and stakeholders. These include communities, governments, port authorities and businesses facing significant financial, time, opportunity cost, resources and capacity constraints (ARQII) when formulating a response to climate risks, (Wardekker 2011; USP 2013; PICCC 2015). It seeks to minimise these constraints through reviewing climate change literature and, more significantly, its effect on MSCs. It aims to identify and evaluate the gaps, strengths and weaknesses of similar research.

To address the key objectives of understanding climate change impacts on MSCs, this chapter defines central climate change concepts (section 2.2), MSCs (section 2.3) and disruption risks (2.4). It identifies and evaluates long, (2.5.1) short term, (2.5.2) and indirect impacts (2.5.3) associated with these risks for ports, shipping and other MSC stages, as the key research areas for reviewing existing literature. In Section 2.6 it summarises and evaluates five research response strategies to limit the research scope to climate change adaptation, rather than mitigation, relocation, migration or ecological rehabilitation. It identifies specific, literature established, stakeholder adaptation measures to propose systematic, supply chain strategies. It considers small-island, developing nation constraints by minimising maladaptation costs. It motivates this thesis's research significance in overcoming existing literature gaps and in proposing the further need for an integrated, Pacific MSC, stakeholder method and adaptation solution to climate change (section 2.7). This solution is based on combining climate change and MSC concepts, risks, impact costs then adaptation strategies holistically.

2.2: DEFINING CLIMATE CHANGE

In conducting a literature review from Abuodha and Woodroffe (2006), to Naruse (2011) to Zviely, Bitan and DiSegni (2015), it is observed that myriad perceptions exist of exact climate change implications. This influences different methodology approaches, risk estimations (KRQA), impact costs (KRQB), and potential solutions (KRQC) for affected stakeholders, processes, infrastructure and ecosystems. Inconsistent definitions and understanding over climate change concepts complicate the central objective of providing further research towards understanding these impacts on MSCs for affected stakeholders. This may cause them to underestimate or exaggerate associated consequences. Examples potentially exaggerating risks, often justifying the need for further adaptation funding, include Pratt and Govan (2010), Greenpeace (2012) and the World Bank (2012). Murray (2010) minimises true risks for St Lucia's coastal economy; through aiming to attract trade and investment. These risks add further uncertainty and asymmetrical information to developing nations, especially Pacific islands e.g. Niue, Tonga, Palau and Nauru. To reduce potential uncertainty, it is essential to define and answer: what is climate change?

The IPCC (2015) assessment report and 2012 updated version of the UNFCC define climate as:

> 'The statistical measurement of the mean and variability of meteorological variables such as temperature, precipitation, wind speed and direction, atmospheric pressure and others over a period of time ranging from months to billions of years.' (UNFCCC 2012, pg. 3).

Climate change was defined by the IPCC (2012) as:

> 'An alteration in the state of the climate that can be identified by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer."

However, this was updated by the IPCC (2015) to the now generally accepted definition:

> 'Any statistically significant and prolonged alteration in either the variability or the mean of the climate, persisting for an extended time period (frequently defined as decades or longer), considered directly or indirectly to primarily occur from anthropogenic causes, that modifies global atmospheric, land and oceanic conditions in contrast to climate variability which relates to natural causes' (IPCC 2015, pg.3).

Alternative definitions of climate change include: 'Climate change refers to a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods.' (UNFCCC 2012). SPREP define it as 'Changes in the Earth's climate due to human activities or natural processes that are already occurring or predicted to occur.' (SPREP 2011). It is also defined as 'Change in the pattern of weather, and related changes in oceans, land surfaces and ice sheets, occurring over time scales of decades or longer.” (Australia Academy of Science 2015)

The emphasis shifts towards specifically connecting it to human activities. Consistent definitions combined with understanding climate change may further assist supply chain stakeholders. These frequently cite unfamiliarity with the process, costs, diverse methods and risks of climate change due to conflicting approaches by academics in an increasing number of research studies. These provide a significant constraint to prioritising action, e.g. Bojinski *et al.* (2014), Kettle and Dow (2015) and Kumar and Taylor (2015). A consistent structural approach is further emphasised by a number of established climate change impact studies. (US Environmental Protection Agency (USEPA) 2008; Policy Research Corporation 2009; ADB 2013). These studies concentrate on defining climate change’s process, prior to defining and assessing subsequent risks, impact costs and solutions.

Without consistent definitions and understanding the process, stakeholders may fail to diagnose emission sources which they can mitigate or risks requiring adaptation. Boesch, Field and Scavia (2000) consider another definition risk of possibly exaggerating climate change event disruption, recovery and adaptation costs. These stakeholders may fail to understand the true significance for MSCs. A small minority of academics; particularly in Australia and the USA, denies climate change’s existence, considering it a natural phenomenon of climate forcing and climate variability. However no credible research evidence against climate change has been located, actually justified and officially adopted as a legislative policy (even among sceptics). The IPCC findings were agreed by over 170 nations, and myriad other research sources officially affirm climate change’s existence as primarily anthropogenic rather than natural (IAPH 2011; World Bank; 2012; IPCC 2013).

This thesis accepts climate change as the prime risk for global supply chains, especially for Pacific small-island, developing states. It accepts the globally established scientific consensus of academic (Nursery-Bray *et al.* 2009; Messner *et al.* 2013; Seto *et al.* 2013) and technical sources (Island Friends Ltd. 2006; International Climate Change Adaptation Initiative (ICCAI) 2011; IPCC 2015), used as baseline assumptions for the IPCC (2015) report. These standardise this process as primarily anthropogenic or created by human beings as a direct/indirect consequence of human activities. It includes emissions, pollution and the physical process/acceleration. This definition infers MSC stakeholders could affect the rate/costs at which supply chains are exposed to potential risks, as a further incentive to prioritise a response to climate change. This thesis considers climate change as a baseline condition established by global evidence and scientists of the ICCAI (2013), the IPCC (2015), the Australian Academy of Technological Sciences and Engineering (2008), Australian Government Bureau of Meteorology and CSIRO (2015), (WMO 2015). It is accepted among all Pacific island governments with official adaptation policies as stakeholders currently experience direct consequences of climate-related, natural disasters.

Emissions and other climate change consequences adversely affect global, regional and individual systems. This is confirmed by SPREP (2012), World Bank (2012), Pacific Islands Forum (2013), SPC (2014) and the IPCC (2015). Direct emissions refer to emissions released as direct output from a point source, sector, activity, system or technology. Indirect emissions refer to those attributable to end user energy and associated production. These subsequently influence the atmosphere, biosphere, cryosphere, land surface and hydrosphere, related ecosystems, economies and future population. They affect future commodity resource bases, coastal protection, economic activity and seaborne trade levels. Economically, many primary resource commodities including seafood, coconut products, fruit, timber, copra and pearls (SPC 2014) will be adversely vulnerable to anticipated climate change risks for the 'global ocean ecosystem'. In the absence of a formal literature definition, this review proposes this refers to the natural interaction of all biological, maritime organisms with non-sentient ocean and coastal, environmental resources. These resources form the global ocean economy and MSC's foundation. This thesis justifies its conceptual contribution to existing climate change, impact studies based on current supply chains that globally experienced significant disruption risks to minimise projected impact costs.

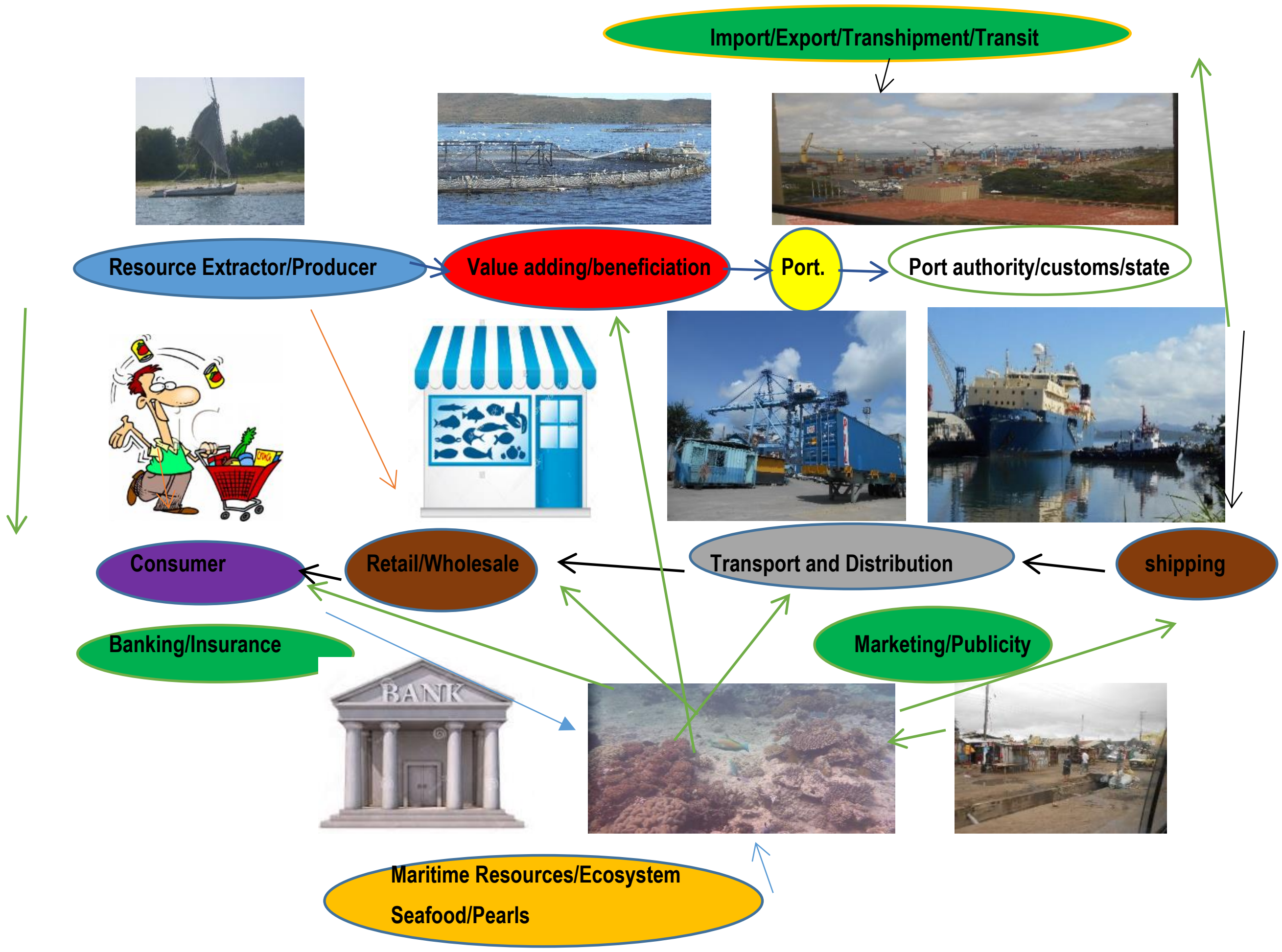
2.3: DEFINING MARITIME SUPPLY CHAINS

In order to answer KRQA-KRQC, it is essential to first define a supply chain. Brooks *et al.* (2012) interprets supply chains as a system of organisations, people, technology, activities, information and resources involved in moving a product or service from a supplier to customer. Based on reviewing Waters (2003), Wang (2007), Thongrattana (2012), Accenture (2013) and BSR (2014), this thesis extends this definition. A supply chain is defined as a system through which a commodity or commodities is produced, transported, processed, distributed, sold and eventually utilised or consumed, (occasionally recycled). It connects initial, producer supply with final consumer demand, through ports, shipping and the associated economic hinterland. For this research's context, an MSC is based on complete dependence on ocean resources from production to consumption and exports. This thesis provides a theoretical departure from previous studies which identify the potential impact of climate change on ports, as only one maritime supply chain stage. Examples include Alfredini *et al.* (2013), Chhetri *et al.* (2015) and Smith (2015). Although applicable to general supply chains, by focusing on Pacific MSCs this simplifies identifying costs across an entire supply chain. This is further developed and defined in Chapters 3-8.

The 'maritime' aspect of MSCs represents this thesis's recognition for Pacific case studies as the majority of its economy, trade and supply chain process, are geographically, economically and physically conditional upon the maritime sector. This contrasts with continental land masses, which incorporate considerable land-side supply chain activity, functions and infrastructure. An example of a simple commercial MSC is presented in Figure 2.1. The concept can be defined for a commodity being traded throughout a MSC and applied to specific, Pacific island, case studies. A commodity or product is first extracted from its source such as seafood harvested from the ocean in a producer/resource extractor stage for various Pacific islands. If not sold or transported directly, it can be processed in value-adding (fish oil) or combined with others in manufacturing. For the Pacific, according to Faletau *et al.* (2012b), SPREP (2014) and SPC (2014), the majority of products directly pass through a port stage to pay customs/port duties and comply with state regulations prior to a shipping stage. A supply chain commodity is transported via shipping, and road/rail intermodal transport locally; transhipped, imported or exported, before being further processed or sold to retailers. The final stages include the commodity's sale to customers/consumers. Those not completely consumed or utilised can pass to a waste disposal or recycling stage.

Throughout all stages, a commodity's flow is influenced by and influences local and global finance/insurance access and publicity or marketing. This affects consumption, production, economic demand and supply (Zondag, Bucci and Gutzkow 2009; Marshall *et al.* 2013; Furlow and Potter 2015). The extent to which climate change presents a significant disruption threat for all stakeholders from producer to consumer will be examined by this literature review and for specific Pacific case studies. Through defining a MSC, these stakeholders may further appreciate the need to prioritise climate change adaptation. Even if assets, locations and staff are not exposed directly, other supply chain stages, which they depend upon may be affected, (as Hamilton 2011 emphasises).

Figure 2.1: A Maritime Supply Chain



Source: Author

As investigated in Scott *et al.* (2013), Ng *et al.* (2013) National, Cooperative Freight Research Programme (2014) and Dyer (2015), understanding a MSC's intended purposes assists in determining how all stages and stakeholders are potentially affected by climate change risks. Consulting relevant stakeholders to determine individual requirements, ensures this approach can be applied, with similar constraints, concerns and risks, at minimal transactional, research and opportunity cost across other MSCs. Stakeholder consultation forms part of a climate change, literature method based on Tompkins, Few and Brown (2008), Godwin (2011) and Smith (2015) and evaluated in section 3.2. Their generic requirements have been shown in survey studies e.g. CSR (2011), Gray *et al.* (2014), Accenture (2014) and BSR (2014). Regardless of climate change, these stakeholders require certainty functions will exist with minimal disturbance risk. They expect stakeholders involved are sufficiently informed, prepared and aware. These stakeholders anticipate they will not lose any functional requirement or be adversely affected by any related supply chain changes; which this literature review extends to any response approach chosen by stakeholders including adaptation.

According to Kreie (2013), Dyer (2015) and Finucane and Keener (2015), these functions need to occur with minimal financial, time and opportunity cost, maximum throughput efficiency and productivity for all offered facilities and services. This must apply regardless of the port type, nature and volumes of cargo throughput, vessel/transport type and cargo characteristics serviced, to connect to the global MSC. Fleming *et al.* (2014) notes it requires an organisational structure, resources and capacity capable of efficiency, speed, reliability, flexibility, security and other stakeholder requirements when considering an Australian seafood supply chain. It is one of the few sources identified considering how requirements might be substantially altered, reduced or paralysed by increasing port congestion, dangers to shipping and other projected impact consequences identified in section 2.5. To adapt to climate change, MSC stages will need to be consistently upgraded and adapted wherever possible. It must enhance potential supply chain resilience to disruption risks. It should minimise time, externality, congestion and user impact costs.

2.4: MSC RISKS ASSOCIATED WITH CLIMATE CHANGE

A central, climate change literature concept includes the exposure of various economic sectors and activities to risks. This is followed by the impacts for ports, shipping and other supply chain stages for an entire MSC in sections 2.5 onwards. This section concentrates on defining key concepts of risks and vulnerability. It particularly concentrates potential implications of globalisation for increasing risks across a global supply chain, from exposure to a localised risk event. To standardise definitions, this chapter defines vulnerability based on the UNFCCC (1999), SPC (2013) and IPCC (2015) as:

> 'The degree to which ocean, coastal, natural and human assets, systems, individuals and species are susceptible or exposed to, incapable of or unable to adapt, mitigate, assimilate and respond to potential adverse costs, risks and consequences of climate change.' (pg. 22).'

Risk is consistently defined as the repeated probability or likelihood of an event occurrence combined with its consequence, across relevant research studies. These include the UN Environmental Programme (2008), UN Economic Commission for Europe (2014), Chow and Brinkerhoff (2015) and IPCC (2015). Climate change therefore possesses significant physical survival and uncertainty risks to geographically vulnerable ports, shipping and other MSC stages. This is affirmed by Lal (2011), Malione (2013) and Field, Barros and Mach (2014).

For literature concentrating on disruption, two recurrent climate change risks are identified based on time horizons to address KRQA. Forfas (2010), Anderson (2012), Garnaut (2012) and Thomas, Albert and Perez (2013) focus on risks with incremental physical variable effects/changes, which lack a formal literature identified definition. This thesis refers to risk events associated with long term impacts. These includes sea level, land, sea and atmosphere temperature, current and wind velocity rise, changes in sedimentation and wave energy. These often require less immediate priorities, constraints and mitigation or adaptation strategy responses over a longer time period of years, decades or longer. A second category identified focuses on unpredictable risks associated with short term, sudden impacts, e.g. related natural disaster events such as storms, tsunamis, typhoons, cyclones, droughts, heatwaves and landslides. These offer greater, more direct risks and impacts necessitating short-term adaptation, resilience and mitigation strategy responses, and present a direct threat over a year or less (Boesch, Field and Scavia 2000; Fletcher *et al.* 2013; Gero *et al.* 2013). The risk of changes in species migration and biodiversity loss poses seldom considered costs for affected stakeholders. To address central MSC disruption risks as KRQA for stakeholders it is necessary to include both short/sudden and long-term risks. Numerous sources focus only on one-time horizon, including Godwin (2011) Brooks *et al.* (2012) and Jha and Stanton-Geddes (2013). The specific impacts associated with the uncertainty, probability and consequences for these events will be identified and analysed in section 2.5 for ports, shipping and overall MSCs.

One advantage of defining a global MSC to stakeholders is it indicates the potential magnifying of climate change risks to each MSC stage. Increasing globalisation of a commodity's trade has significantly increased disruption risks and potential opportunity costs, to extend beyond just a simple MSC. It increases significantly the number of stages, which depend on unimpeded trade flows from producers to consumers, via ports and shipping. Wang *et al.* (2007), also propose port logistics as a network interconnecting not just the seaport, but the city and dependent surrounding hinterland from start to end user in the global supply chain. This is subject to ever changing, stakeholder requirements in a Post-Panamax vessel size and Globalisation Age. Other globalisation aspects anticipated by Johnston, Burton and Baker-Jones (2013) to worsen climate change consequences include the increased vulnerability of supply chains from point of origin to point of consumption from localised emissions, climate and non-climate drivers. These aspects include global economic consequences of related disasters e.g. a cyclone in Vanuatu cyclone, a French Polynesia storm or a New Zealand earthquake. Previously the economic, social and environmental impact costs would have been correspondingly far smaller, being more localised.

Figure 2.1 illustrates a general MSC with transhipment cargo volumes and connections to the local and national economic hinterland. This framework is consistent with Van Klink's 1998 theory of port evolution from a city with limited port authority to a port area with value adding/manufacturing base. It then expands to a port region with port city. Finally, it may become a port network across international ports. It extends to an advanced, regionally dominant, main port in a borderless, globalised economy, through various stages of economic and hinterland development, port growth and integration. Globalisation implies greater uncertainty of climate implications. These risks need to be measured in terms of greater uncertainty for MSC costs and time. They arise not just through delayed vessels and increased port congestion as other studies imply, (Fairhurst 2008; Cape Town; Hearn 2012: Singapore and Awuor, Orindi and Adwera 2014: Mombasa) but throughout a commodity's supply chain.

Hiranandani (2012), SPC (2013) and UNCTAD (2014) project significant global seaborne trade and economic activity growth. However, they downgrade or ignore the risks to supply chains from climate change events via increasing trade diversion from local to multinational corporations, specialisation, firm market concentration, outsourcing of labour, capital products and investment flows. These potentially increase a specific event's associated risks and impacts. Ye and Abe (2012) define global supply chains as distribution links between firm suppliers, distributors and consumers. They contend stakeholders' associated risks and impact costs significantly multiply from increased trade volumes, into fewer participants globally. This further expands related costs and risks from any temporary or permanent interruption. Examples include increasingly uncertain impacts identified by Agrawala *et al.* (2011), Australia Government Bureau of Meteorology and CSIRO (2014) and BSR (2014).

2.5: CLIMATE CHANGE IMPACTS ON MSCs

Sections 2.5.1 2.5.2 and 2.5.3 identify significant impact costs associated with MSC risks. Climate change generally presents these risks to global and Pacific ports, shipping and overall supply chains through influencing exports, imports and transhipment values, qualities, volumes, related revenue and fixed/operational costs (Jones 2013a). These projected impact costs will therefore influence the continued physical survival, commercial profitability and other requirements for global and Pacific stakeholders, across all MSC stages in Figure 2.1. In failing to define and recognise both risk event types and associated impacts in existing studies, current stakeholders are often climate change averse. Many fail to adapt to risk uncertainty according to Becker *et al.* (2013), Seto *et al.* (2013) and the UN Economic Commission for Europe (2014) for international transport networks. Concentrating on a single risk type underestimates impacts identified in sections 2.5.1 and 2.5.2. This increases eventual disruption and adaptation costs involved, if response actions are not perceived as necessary by stakeholders. To completely adapt to climate change, this thesis contends both disruption risk and impact types need to be prioritised and evaluated for MSCs (KRQA).

2.5.1: Long Term Impacts of Climate Change on MSCs

Other studies have extensively concentrated on various disruption risks effectively impeding port or MSC performance. Gurning (2011) cites severe weather, customs, port strikes, port congestion, earthquakes and port equipment. To further propose a research methodology and adaptation strategies for these maritime risks, this review's theoretical framework extends upon Savonis, Burkett and Potter (2008), Hahn and Frode (2011), Attavanich (2013), European Commission (2013) and Scott *et al.* (2013). These first concentrate and identify only specific risks for ports, before assessing direct consequences for disrupting various stages and stakeholders. Projected long term, risk events threatening ports, shipping and other MSC stages, include SLR, temperature, humidity, precipitation, changes in current, wave energy and sedimentation according to IPCC (2015). These events and associated long-term impacts/consequences are summarised in Table 2.1 and analysed further in this section. This table was devised by a combination of candidate innovations and existing Chapter 2 identified sources. This approach provides the advantages of establishing how particular port functions and stakeholder requirements might be adversely affected by climate change.

As summarised in Table 2.1, the long-term risk events and associated impacts for ports include sea level rise which creates a progressively smaller, total port surface area, pavement and foundation damage from flooding. Examples include ADB 2010, Sekimoto *et al.* 2013; Karambas 2015). From Chapman and Pett (2009), Shand (2011), Kitty (2013), Mojafi *et al.* (2015) and Ng *et al*. (2015). Flooding impacts can create reduced port, surrounding road, rail, shipping, air transport, utilities, and supply chain land area and access. Changes in sea spray, wind velocity, waves, humidity and temperature from storms, tsunamis, heatwaves and others may further decrease potential port activity from corrosion and other damage to local and cargo transport vehicles and equipment (Adger 2007; Humphrey 2008; Hoshino *et al.* 2015). Physical damage to port infrastructure, vessels, equipment, cargo and related utilities (water/electricity/sewerage) for all risks from increased sea spray and erosion, may create idle infrastructure/equipment capacity, delaying port/supply chain performance (Becker 2014; Chhetri *et al.* 2013; McEvoy *et al.* 2015). These may cause significant damage to port and associated supply chain infrastructure, services and performance, the quantity of cargo throughput through the port, the composition/quality of these commodities and physical damage posed to cargo (Kitchen 2008; Hale and Twomey 2013 and Inoue 2013).

Other long-term risks and associated impacts include increases in temperature, humidity, wind velocity, currents and precipitation frequency, duration and intensity. These risks can significantly delay port operations over an extended time period, creating a high economic impact cost on the surrounding economic hinterland. USEPA (2008) outlined this for United States ports. These risks may create further physical damage and delay, impact costs to port processes directly and MSCs indirectly. Infrastructure and other assets progressively lower climate resilience from repeated physical exposure over time, as detailed by Love, Soares and Puempel (2010), Anthoff *et al.* (2011) and Omer (2012). According to Cahoon and Chen (2014), increased sea levels, precipitation and wind velocity can impair crane and other equipment, operational capacity and mobility, and twist road and rail infrastructure. It may displace containerised cargo and hinder ro-ro and other cargo loading/unloading, storage and distribution functions.

Potential MSC risks, with associated long-term impact costs identified by literature, are summarised in Table 2.2 (KRQB). Various physical, economic, financial, legal-policy, technological, psychological, health and safety, education, training and environmental impact costs may influence stakeholder adaptation solutions. A projected increase in storms, precipitation and surface run-off may damage cargo and passenger terminals, equipment, vessels, cargo, wharfs, piers, bridges, roads, rail, and port security cameras. This further provides economic, profit, environmental, physical survival and direct security risks to affected users (Blackhurst *et al.* 2005; Gurran, Hamin and Norman 2012; Connor *et al* 2013). Sierra *et al.* (2015) predicts increased wave oscillation and turbulence plus decreased circulation from prolonged wind velocity. This may further complicate vessel navigation, especially through narrow/congested port channels, increasing associated berth occupancy, port, cargo, transport, equipment and idle capacity costs. Wind velocity increases may further delay or damage terminals, port and customs authorities, directly affecting profits. Increases in information uncertainty and planning/emergency responses may exist through significant damage or interference to communications, information and hazard warning systems. This further affects intermodal connections and Pacific and global supply chains through decreased profits, increased congestion and costs, (Hanson and Nicholls 2012; US Government Accountability Office 2015), as detailed in further sections. Higher wind velocity, humidity and temperature may increase port dust and related cleaning/storage protection costs.

Maritime disruption risks and related long-term impacts may initiate changes in ocean currents, wave energy actions, coastal erosion and channel sediment, higher temperatures, humidity and moisture from precipitation (McGregor *et al.* 2011; GEF; UNDP and SPREP 2011; Petrini 2015). Increased salinity from ocean acidification, humidity, temperatures and precipitation may further increase port infrastructure, transport, equipment and cargo erosion/corrosion rate costs. Australian Government Department of Climate Change (2010) anticipate particular weakening of metal based over more resilient concrete/timber-based structures from sea spray increases, with further associated repair, replacement, maintenance and adaptation costs. This may further gradually impair port functions and environmental resilience or absorption capacity of the related ecosystem. Climateproofing development increases repair, maintenance, replacement and adaptation costs (Airoldi *et al* 2005; Hahn and Frode 2011; Stewart and Deng 2014). Direct long-term risks and associated impacts include delayed or damaged cargo throughput. Therefore, supply chain efficiency and performance is reduced, significantly increasing congestion directly. This reduces profits and increasing other opportunity costs for dependent stakeholders, and indirectly throughout the affected supply chain (Beerman 2010; Aifadopoulou 2014). These long-term impacts gradually challenge each stage's capacity to satisfy requirements of accessibility, reliability, certainty, speed and frequency. This ultimately reduces port productivity, efficiency, equity, user cost and inter-port competitiveness.

Table 2.1. Climate Change Long Term Impacts for MSCs

Gradual Physical Climate Risk Events (Increases in frequency and intensity)	Impacts on Port	Impacts on Shipping	Impacts for MSCs
SLR	-Increases in coastal erosion/ -Reduced port and surrounding economic hinterland/supply chain physical land area and access. -Physical damage and weakened climate resilience from potential flooding for port infrastructure, equipment and services. -This creates increased repair, maintenance and replacement costs	-Increased water depth/reduced bridge clearance creating changes in vessel navigation route and minor increases in fuel/bunkerage costs	-Physical damage, delay, congestion, financial and opportunity costs to individuals, cargo, property, equipment and port functions to all supply chain stakeholders for all risk events **Changes in** -Inputs/Resources, -Labour -Processes -Production Outputs -Outsourcing -Distribution/Sales -Access to Financial Capital -Profits and Costs -Customs processes -Legislation
Precipitation	-Increased duration may create flooding and increased surface runoff creating temporary/permanent physical damage, delay and other port disruption costs. -Increased damage to exposed physical commodities and port equipment This creates increased port and related supply chain performance delay and impact costs	-Increased precipitation may discourage strategic vessel callers. -Increased physical vessel fatigue, commodity damage and reduced navigation –increased vessel delay/slow steaming, insurance, costs	
Temperature/Humidity increase	-Weaker structural infrastructure resilience and possible physical damage oxidation and corrosion increasing over time. -Potential health/safety risk to port labour, equipment, management and technology decreasing port performance	-Potential physical commodity damage and increase in energy consumption of reefer/containerised cargo throughput	
Wind velocity	-Risk to cargo handling labour, container stacking crane gantries, equipment	-Risk to physical vessel docking, pilotage, tugs turning basin movement	
Change in currents, wave energy, ocean acidification and sedimentation	-This disturbs port ecosystems and physical risk exposure; maritime resources and habitats affecting related commodity yields.	-Alters water flow, complicates vessel navigation, higher tug mooring and pilotage costs. Increased hull cleaning, maintenance and repair costs.	

Source: Author.

Whilst the majority of established literature sources have analysed projected climate change impacts for ecosystems, economies, ports and supply chains, very few such as Rodrigue (2010), Bhaskar, Cahoon and Chen (2014) and Newell, Nuttal and Holland (2015) have considered focusing specifically on the shipping sector. This study conceptualises including these links in the global MSC, delivering goods and services from producer to consumer. This thesis further distinguishes itself from Savonis (2014), Smith (2015) and Wang (2015), which restrict their focus to ports. It evaluates projected risk events and associated impact costs for shipping (section 2.6.4) as a key MSC distribution stage. Long-term maritime risks and related costs are summarised in Table 2.2, which identifies long-term impact costs to vessels and shipping companies as similar to ports and other MSC stakeholders. Costs also include gradual changes in physical damage and port access, market demand and supply, operating schedules and adaptation measures. Examples of long-term impacts include potential physical vessel damage from increased frequency and intensity of gradual risks, including increases in wave energy, temperature, wind velocity, sea levels and acidification. Risks enhance vessel thermal expansion and associated structural fatigue. This is detailed by Figliozzi and Zhang (2009) for containerised vessels, Port of San Diego (2013) and Phillips (2015). Additional impact costs include restrictions in port access/availability from risk exposure over time, if adaptation is not prioritised. SLR is also expected to affect navigability through reduced bridge clearance, e.g. ports such as Sydney, Brisbane and Auckland, limiting vessel height. This may necessitate expanding the frequency of bridge openings plus increased clearance for new bridges according to Savonis, Meyers and Potter (2012). It may affect port water depth for approaches/channels influencing vessel magnitudes capable of utilising a port (Correro, Schwartz and Wenger 2011). Vessel navigation may also be impaired through submersion of navigational aids. This affects shipping operations and related MSCs as cargo loading/unloading, storage, customs processes; transport and distribution functions are delayed or averted.

Long term, specific impacts identified for shipping include reduced navigational safety and altered trade routes. Increasing hazardous coastlines and reduced visibility exist from projected increases in precipitation, wave, wind and current energy (Rossouw and Theron 2009). These risks may increase the need for additional berth depth at harbours. It also requires physical vessel configuration and technology to enhance resilience, as vessels become more exposed to the stresses of increased precipitation intensity and frequency. This presents higher associated swell and waves, humidity and temperatures, wind and current direction/velocity (Jansen 2013; Newell, Nuttal and Holland 2015). Projected coastal ecosystem erosion and sedimentation increases may necessitate more frequent dredging, to avert further navigation costs (Millerd 2011). Alternatively, increasing water temperatures may accelerate hull organism and sedimentation growth rates, increasing hull cleaning costs. However, previously unmentioned changes include species migration and biodiversity variations may cause habitats to change to existing shipping, routes, coastal areas and ports, as climate change significantly disrupts ecosystems (Chapters 1, 2 and 5). For example, in Hobart 2016 Antarctic whales disrupted shipping owners with threats to navigational safety and delay demiurge costs of $5000 per vessel per day, as community members and state laws necessitated safe species relocation.

Long-term risks and associated impacts for other MSC stakeholders and stages are categorised by this thesis in Table 2.1, as impacts to inputs, processes, production outputs and distribution/sales. These are divided as cost consequences for producers, retailers and consumers in Table 2.2. Affected inputs include reduced physical access to natural resources over time, from direct ecosystem and biodiversity loss risks, identified by Lam and Yip (2012). Potential risks and connected, economic impact costs are enhanced by global corporations, which outsource production, labour and resource inputs. Risk event changes will change agriculture and aquaculture economic yields, associated cargo throughput and production, especially for Pacific MSC (SPREP 2013). As Table 2.2 summarises, increased risk exposure may influence supply chain, production processes through reduced labour and operation productivity. It increases damage, delay and congestion impacts to infrastructure, equipment and technology. These may create higher associated maintenance, repair and adaptation, impact costs (Khosa 2013). Production output capacity, performance, speed, composition, quality and quantity may also be affected through disruption risks to cargo throughput (Lewis, Erera and White 2014). For interlinked beneficiation supply chain stages, these create higher associated transport, storage, insurance and opportunity impact cost and lost profit consequences.

Table 2.2: Climate Change Impact Costs on a Commodity Supply Chain

Producers	**Retail/Wholesalers/Intermodal Transport**	**Consumers/Customers**
Physical damage, delay, congestion, financial and opportunity costs to individuals, cargo, property, equipment and port functions to all supply chain stakeholders		
Inputs/Resources, Labour	Transport, storage and other costs	Demand/Supply
Processes	Insurance costs	Price
Production Outputs	Reputation risk	Life/Heath
Outsourcing	Opportunity costs	Availability
Distribution/Sales	Trade diversion/creation	Employment/Consumption
Access to Financial Capital	Access to Financial Capital	Access to Consumer Credit
Profits and Costs	Profits	Changing Consumer Preferences/Behaviour

Source: Author

General impact costs for customers/consumers are summarised in Table 2.2 (Codiga and Wager 2011: Hawaii and other US Pacific islands; Cox 2013: Cook Islands; Accenture 2013). These costs include a possible decrease in economic demand and activity from a substantially lower population; lower employment, price increases and reductions in resource availability. Climate change is expected to affect resources supplied and change markets from trade creation/diversion. This provides economic benefits for flexible firms to adapt. It offers significant opportunity and other costs to those not so prepared, according to Jansen (2013). Not just producers, retailers and logistics distributors but consumer preferences and habits may also be influenced to become more environmentally sustainable, to mitigate emissions slightly or penalise non-reformers. Ng *et al.* (2014) also mention an indirect effect of increasing public climate change awareness has increased environmental activism in boycotting commodities e.g. coal for Australian ports. This creates a further increasing supply and decreasing demand, impact risk for each dependent supply chain stage.

Climate change is likely to influence supplier decisions of sourcing material cost, type (if climate sensitive), quality and quantity including factors such as water supply, geographical location, distance (if ocean or large land-based), size, environment and risk negotiating, buying/pricing, strategic demand and supply (Haverkort and Verhagen 2008; Miolia, Marra and Ciuffo 2011; Khosa 2013; Lee and Kim 2013; BSR 2014). Zondag, Bucci and Gutzkow (2009) consider how customer demand and producer supply expectations or requirements may shift in adapting. This affects pricing, sales, distribution, order management, fulfilment and distribution along with the degree of customisation port users might require, as they may become potentially more or less flexible in response to climate change. The speed at which a stakeholder can satisfy demand, provide services, alter schedules and requirements involves being responsive, adjusting the price and quality/quantity of services for the Pacific and globally. This response rate is considered to depend upon the extent to which they prioritise climate change adaptation and resilience by an increasing number of sources (GEF, UNDP and SPREP 2011; CSR 2011; Rozensweig and Horton 2013; Ng *et al.* 2015).

The economic impact consequences of disrupting any commodity include increased customs, cargo handling, storage and distribution, port authority and transport delay, time, opportunity and reputation costs. This is pointed by Pacific case studies e.g. Gero *et al.* (2013). Financial impacts threaten profits and port revenue from possible port congestion. This creates risk and uncertainty for all dependent stakeholders adversely influenced by the loss, damage or suspension of trade. Gurning and Cahoon (2009) analysed this uncertainty for disruptions to an Australia-Indonesian wheat supply chain. Additional indirect impact costs to port authorities and other stakeholders include climate change risks to agriculture, aquaculture, forestry, transport, infrastructure, cargo, equipment and the overall economy. Examples include lost wages, business delays and interruptions, increase in operation, risk management, training and capital expenditure associated with port recovery, adaptation, repair, maintenance and cleaning costs, (Haverkort and Verhagen 2008; Reis 2013; Loh and Thai 2014). This further reduces overall MSC performance and associated economic activity.

Becker (2014a) identifies subsequent impact costs for which it is difficult to obtain precise, quantitative cost estimates. These include reduced quality of life, environmental damage, loss of cultural heritage, essential infrastructure and services including labour productivity (even experience and skills from loss of life or damage). Becker cites customer reputation, loyalty costs from key port users, reduced inter-port competitiveness and other opportunity costs. Higher psychological impacts also include a productivity loss for ports and supply chains due to a reduction in spirit/morale from a climate change event aftermath. The actual impact costs, risks and extent of adaptation required is conditioned by previous and current disaster experience, information resources and preparation. (Becker *et al.* 2013). It also however includes the will and capacity to acclimatise, enhance resilience or respond. An alternative psychological risk presented by Stratford (2013) and Ni (2015) may exist for the affected exposed coastal community. Climate change may temporarily possess an economic, health, social and security threat from an increase in potential migrants, especially for residents of Polynesia, New Caledonia, Micronesia, Marshall Islands and Palau, mostly a few metres above sea level. These might seek to escape to Australia, New Zealand and the USA, to escape the costs of related natural disasters and submerging of nations and MSCs.

Overall supply chain, performance cost losses may expand significantly from submerged, damaged or destroyed facilities, equipment and cargo and from reduced physical access. This is identified through the following indicators of port productivity and activity by Jones (2013b) and Dyer (2015). Indicator examples include vessel waiting time for berths, average cargo dwell/clearing time, average customs clearance and processing time along with vessel, road and rail turnaround time. Average berth occupancy rates for existing vessels physically exposed to risk events' aftermath is expected to increase temporarily from supply chain congestion. It is expected to contract for the number of new vessels entering a port. Gross crane moves per hour, number of container moves per ship working hour, tonnage of cargo carried per running metre of quay and per unit of cargo employed/worker may decrease significantly from increased wind velocity and storm damage. Many operators being risk averse (UNCTAD 2011; Ports and Freight Logistics Council of Western Australia 2014), may adapt through reduced output and minimising exposure to potential risks and costs.

Average cargo capacity utilisation may become lower from reduced agricultural and fishing yields from droughts and heatwaves. This creates greater downtime for port labour reducing productivity, port and cargo dues and user willingness to pay for facilities, (Becker 2014b). This can affect agriculture and other economy production variations in demand and supply through submerged crops, port, transport and storage infrastructure, reducing cargo throughput and revenue. Further impacts include reputational loss and subsequent possible trade diversion/loss to other less vulnerable forms of transport e.g. shipping/air from road/rail, affecting port trade flows. This was noted by Lam and Su (2015) as decreasing port competitiveness. Alternatively, trade may divert to ports providing greater flexibility, fiscal resources and commitment in prioritising adaptation solutions. Therefore, ports and dependent MSC stakeholders are expected to experience significantly higher total costs per year. This arises from physical commodity and facility, damage, time delay, reputation loss, congestion and other impact costs from decreased port activity.

This review identifies another long-term impact across MSCs for customs processes. Historically, customs protected trade against foreign competitiveness; acquired revenue and facilitated legitimate commerce, while defending society against potential security and other threats. Dyer (2013) noted problems faced by current authorities specifically include ensuring trade facilitation and economic competitiveness through lower commercial barriers, whilst simultaneously achieving securitisation of the entire global supply chain against risks threatening cargo. Climate change potentially creates the greatest disruption risk for customs and port authorities through potential congestion, physical damage, delay, trade diversion, reputation and security loss. This threatens these core functions throughout the global MSC, being particularly significant for global customs authorities with scarce labour, technology, equipment and other resources, (Goodger 2013; Jones 2013; Dyer 2013). Yet it is ignored by many customs authorities as a risk, even the Australian Government Customs Service (2008) in its 2015 strategic outlook.

An increasing number of sources, (Eide and Endresen 2010; Taylor and Phillip 2011; Simpson, Grubele and Amerasekara 2013), are highly limited in effectiveness in responding to projected climate change impacts, concentrating on vessel emissions' mitigation rather than adaptation in their proposed solutions. In response to global climate change contributions by international shipping, the IMO, MARPOL 1978 Protocol Annex VI aims to significantly reduce CO_2, SO_2 and NO_4 emissions, using scrubbers, from 2015 (UNCTAD 2014). Most of the world's registered shipping fleet have indirectly indicated a willingness to prioritise mitigation via the ratification by the main global flag states of Liberia, Panama and the Bahamas (Wright 2013). According to UNCTAD (2014) MARPOL will target a minimum efficiency and emissions output reduction and control requirement, in terms of CO_2 emissions per capacity mile for new vessels. It will require using mandatory Ship Energy, Efficiency Management Plans and Energy Efficient, Design Indexes. This includes integrating new technical improvements from implementing the 1999 UNFCC to incorporate vessels. Increases in double hull, energy efficiency and biofuel requirements, along with environment and port regulations, provide a financial compliance cost. It also provides further delay, reputation and opportunity costs to cargo throughput from this increased pressure and complexity in adapting. Lawrence and Manning (2012) affirmed these impose significantly expensive, regulatory compliance costs of additional legislation for Pacific nations, port authorities and local shipping companies with limited fiscal, labour, legal and governance institutional capacity, already having to prioritise other adaptation measures. Ng, Cahoon and Chen (2014) suggest a failure of shipping stakeholders to adapt to climate change risks threatens profits further from reduced economies of scale, specialisation, efficiency and correspondingly lower freight rates from reduced cargo throughput. Increased research, information and communication cooperation and sharing of more eco-sensitive port and cargo handling equipment, technology and transport adaptation solutions are suggested for industry by Linennluecke, Griffiths and Winn (2013). These and other measures can further assist Pacific and other developing nations to minimise fiscal and other adaptation constraints for MSC stakeholders.

2.5.2: Short Term Impacts of Climate Change on MSCs

This section identifies short-term risks for MSCs, concentrating on storms, tsunamis, cyclones, heatwaves, droughts and landslides as unexpected maritime disruption risks potentially affecting a general supply chain. Table 2.3 summarises more frequent, literature cited, unexpected risks and impact costs for ports. This enhances MSC stakeholder awareness of potential consequences when failing to prioritise adaptation. Sudden risks provide similar damage and other costs to those summarised for long-term impacts (Table 2.2). These differ primarily through greater physical, economic, psychological, health, reputational, environmental and other impacts as threats to lives and facilities. This reduces port demand, capacity and performance throughput for a greater time duration, frequency and intensity. This review agrees with Anderson (2012), Australian Bureau of Meteorology and CSIRO (2014) and UNISDR (2015), that more significant risk events possessing more immediate and costlier, direct consequences require more urgent and decisive action by key affected stakeholders throughout the Pacific and world, not just the port authority/state alone. When adapting, unlike sources which concentrate on generalised adaptation strategies, this thesis recommends a methodology considering the effects and necessary response may also differ in frequency, intensity and duration. They may be temporary or more permanent, direct or indirect for each affected Pacific port, commodity, shipping, supply chain and stakeholder.

The most significant impact costs to ports and shipping are considered here as those to life and property (Table 2.3). These establish a potential economic loss from disruptions to production, consumption, management and labour force (particularly for primary commodities), reducing supply capacity for cargo throughput, (ADB 2010; IAPH 2011; Asia Pacific Network for Global Change Research 2014). This reduces port revenue and physical capacity to undertake port functions with significant, adverse implications via contractions in supply chain trade/economic activity. Other associated costs include possible damage to communications, information and related early warning systems, weakening preparation for further recovery and adaptation efforts (Ng *et al.* 2013; Schuster 2013; Savonis 2014). This thesis proposes an additional reputational cost risk exists. The extent of damage combined with the probability of risk exposure, may reduce business confidence in utilising a port. The more immediate the event, the higher the associated impact cost/p commodity damage; the greater the reputation, opportunity cost. Inadequate climate change responses decrease a port's reputation according to Berle, Rice and Asbjornslett (2011) and Wang (2015). Another sudden impact cost involves a physical threat to providing port bunkerage, water supply and other services causing minor delays to activities. Other port impact costs include increased customs, cargo handling, storage and distribution, port authority and transport delay, time, opportunity and reputational costs. Further costs add lost commercial profits and port revenue from possible congestion, risk and uncertainty (Scott *et al.* 2013; Wang 2015; Smith 2015), which affect shipping and overall MSCs.

Additional short term impact costs in Table 2.3 for shipping, (aside from damage to ports, vessels and cargo), include potential dangers to vessel navigation from increased storms, wave surges and spray/wind reduced visibility creating higher associated economic, tourism, opportunity, legal, technical, environmental costs (Handfield, Blackhurst and Elkins 2007; ADB 2013; Loh and Thai 2014; Dyer 2015). Increased thunderstorms could place pressure on port area lightning deflector systems, lighting and vessel navigational aids. Vessel damage may also occur. Increased damage will also achieve increased construction, repair, maintenance and replacement costs (Ng *et al.* 2013), to restore, shipping or MSC system, after a sudden risk, (Meersman, Van-de-Voorde and Vanelslander 2009; Deloite Access Economics 2013; Becker 2014; Cahoon and Chen 2014). These may create impact consequences such as changes in shipping operations, markets, routes and port pricing, requiring equivalent adaptation responses for stakeholders.

Table 2.3: Short Term Impacts/Extreme Climate Risk Events for MSCs

<table>
<tr><th>Short Term Climate Risks</th><th>Impact Costs on Port</th><th>Impact Costs on Shipping</th><th>Impact Costs for MSCs</th></tr>
<tr><td>Storms/Superstorm surges</td><td>Increased threat to communications, information and early warning systems.</td><td>Physical vessel/port/ commodity damage.
Physical danger to vessel navigation.</td><td rowspan="5">Increased frequency, duration and intensity of long-term impact costs as short term, sudden cost changes summarised in Tables 2.2 and 2.3

Risk Changes In Species Migration/ Biodiversity
Changing Rate of Innovation and Technology
Global economic activity
Changes in Seaborne trade
Changes in access to maritime finance
Changes in global and regional social-political/commercial/ environmental instability.

Increase in insurance premium costs

Changes in economic demand, supply and associated changes in economic activity, employment, production, consumption, exports and imports, inflation and exchange rates affecting possible purchasing power and trade competitiveness.</td></tr>
<tr><td>Hurricanes/Cyclones /Tsunamis</td><td>Physical damage to port infrastructure, vessels, equipment, cargo and related utilities, creating increased construction, repair, maintenance and replacement costs.
Possible physical commodity damage decreasing a port's reputation, loss risk/creating increased insurance costs from reduced business confidence.
Psychological costs, threat to life and property, creating a loss of economic potential, commercial profits, tax and port revenue. Higher Port Costs.</td><td>Higher insurance premium, repair, maintenance, labour, voyage, charter and other costs,
Reduced port access, increased congestion,
Physical navigation risk
Threats to vessel navigation, safety, delays and congestion.</td></tr>
<tr><td>Droughts</td><td>Physical threat to agricultural and fishery productivity reducing potential cargo throughput. Lower water depths may limit channel/port navigation and related vessels
Physical threat to providing port bunkerage, fuel and other services.</td><td>Changes in demand, supply, port profitability and pricing
Changes in routes, markets, trade diversion and reduction,</td></tr>
<tr><td>Heatwaves</td><td>Physical threat to port productivity – health and safety of affected workers/ operators creating idle capacity and other delay costs
Direct threat to physical fatigue of infrastructure, equipment and operations delaying port activity
Damage to information/ communication systems</td><td>Production variations in demand and supply reducing cargo throughput and revenue</td></tr>
<tr><td>Landslides</td><td>Increased soil moisture from precipitation, storms, tsunamis and cyclones can destabilise road/rail/ coastal erosion creating congestion delays from debris.
Public Health Risks from exposed waste disposal sites.</td><td>Physical legal/technical regulatory compliance costs, increased insurance liability costs
Production variations in demand and supply through submerged crops, port, transport and storage infrastructure, reducing cargo throughput and revenue</td></tr>
<tr><td>All Risks</td><td>Operational/financial and reputational cost loss</td><td>Operational/financial and reputational cost loss</td><td>Changes in port pricing, taxes, subsidies to recover costs and finance adaptation.</td></tr>
</table>

Source: Author

A health and safety impact cost could occur from landslides and other risks, exposing waste disposal sites, increasing pollution and posing stakeholder productivity. Landslides could potentially submerge crops and infrastructure and restrict transport access. Health and safety disruption costs to workers and equipment threaten overall supply chain performance from increased temperatures and heatwaves, in creating idle capacity and other delay costs. Increased congestion and public health costs potentially delay cargo further. Safety risks include a direct threat to physical fatigue of supply chain infrastructure, equipment and operations, delaying berthing, mooring, cargo handling and other activities. Esteban and Tagaki (2015) propose this in a coastal engineering handbook to provide specific guidance to stakeholders uncertain how to physically adapt ports. Currently, asymmetrical information and lack of coordination amidst global supply chain stakeholders is noted by Berkhout, Hertin and Gann (2006) and Lehmann *et al.* (2013). This complicates formulating effective awareness and early warning, disaster risk management responses.

As summarised in Table 2.3, Baker and Week (2013) identify further vulnerabilities to specific, Pacific port operations but also to the wider maritime economic hinterland from increasing congestion, reducing capacity and performance and from fewer vessels navigating the port safely. They note as most Pacific vessel energy is diesel fuel-based, workers may lose vehicular or other access for maintenance, repairs and operations. This significantly increases opportunity costs of disruption, for those failing to prepare. Shipping firms will therefore experience increases in maintenance, repair and related insurance premium costs (Kember 2012; Jones, Dundun and Abkowitz 2011), decreasing profitability on a route such as the Pacific. A further impact study limitation is noted for MSCs (Ng, Chen and Cahoon 2014). Unlike Haverkort and Verhagen (2008 for potato supply chains), they ignore impacts on vessel availability due to restricted port access and cargo supply availability. A natural disaster influences decisions to visit a port of containerised, dry and wet bulk cargo, fishing, and other strategic vessel callers including tramp steamers, repair, military and cruise vessels. Swire (2012) and Wright (2013) also focus on potential impacts; not just for creating supply uncertainty but also threatening economic demand, production and consumption for supply chains. Vessels may have to adjust trade routes, markets, commodities and shipping schedules to adapt.

Other short-term impacts for shipping in Table 2.3 consider the cargo type, value, quality and volume may also change from these risks, requiring replacement costs to avert or mitigate potential customer reputational costs from delays. From analysing Millerd (2011), Miolia, Marra and Ciuffo (2011) and Ng *et al.* (2013) this presents an opportunity cost to future business. DeMonie (2005) anticipates increased daily fixed capital and operating costs per TEU, time in port per ship and total shipping cost, increasing reputational loss and financial risks, discouraging customers further. This review advocates cargo load sizes and subsequent vessel, cargo capacity utilisation may decrease. Higher winds and increased wave swell energy may destabilise vessels, especially in the exposed Pacific Ocean and anchorages from Funafuti to Port Vila. Shipping companies reduce profits further from increased stores, fuel consumption and bunkerage costs; crew wages required (including possible health and safety risk premiums from perceived and actual greater risk exposure), voyage and time charter costs. Costs include related administration, information and communication incurred in response to or adapting to disruption event consequences. This threatens a commercially profitable future for Pacific shipping. Continuous disruption risks also threaten locational and technical, economies of scale where shipping provides conventionally the lowest cost per unit of containerised cargo between road, rail, air and sea, which existing solutions fail to address. The IAPH (2010) proposed introducing port emissions, cost pricing as a mitigation solution. Yet this further undermines shipping and intermodal transport, cost-competitive advantages to Pacific MSCs.

According to UNCTAD (2014), average vessel sizes are expanding to exploit economies of scale for global trade. Climate change impacts on Pacific regional shipping may require contingency re-routing or adapting to smaller vessels to reduce vessel emissions (Gurning and Cahoon 2009). Other factors may also encourage adapting to smaller vessels with lower cargo carrying capacity given enhanced damage risks and reduced survival prospects of commercial markets, port infrastructure, populations and land areas for many Pacific nations. Risk events present increased uncertainty for tramp steamers and time/voyage charters. These base profits on avoiding ballast voyages with no/minimal cargo, adjusting to seasonal fluctuations in bulk commodities and irregular demand. However, some marginal callers may benefit from temporary trade diversion opportunities from idle liner vessels (Dyer 2013). It may also increase reputational, trade and transport costs to Pacific liner companies. These companies may have to increase corresponding freight rates but also depend upon greater price stability, a fixed, regular sailing schedule and diverse cargoes, often of high value according to Jones (2013a). These requirements are increasingly threatened by greater congestion and associated delays to required functions; predicted as direct consequences.

2.5.3: Indirect Impacts of Climate Change on MSCs

This study differentiates itself from previous literature e.g. Network for Business Stability (2011), Rosenmund (2012) and Jansen (2013) through distinguishing between the initial, direct impact vulnerability of ports and the indirect implications for affected supply chains when applied to a specific commodity. Direct impacts are defined as:

> 'The total additional consequence, activity, process or variable physically attributed to that initial source at that time and place,' (IPCC 2015, pg. 164).

Indirect impacts are defined as:

> 'Those impacts which are often produced away from, or as a result of, a complex impact pathway.' They may occur outside the specified boundaries or time period of direct impacts.

Indirect impact costs for port and customs authorities include increased congestion from substantially diminished port performance (Cox 2013). A considerable proportion of potentially vulnerable stakeholders often ignore or underestimate financial impact costs of MSC adaptation to climate change (IAPH 2011; Hanson and Nicholls 2012; Becker 2014a; Ng *et al.* 2015). This study overcomes existing literature gaps by identifying further projected indirect costs for shipping and other stakeholders, as solutions require resources to finance climate change adaptation. For the Pacific region with limited fiscal resources, only a fraction of funding can derive from tax revenue. A greater part is needed from private sector capital, aid donors and price increases to consumers and other supply chain participants. Part is needed for port authorities from a possible increase in port and cargo dues. Lam and Notteboom (2012) summarise various international port authority, pricing incentives to reward more eco-efficient vessels and stakeholders, whilst penalising high pollution emitting sources; contributing towards accelerating risks and consequences. Port pricing and tariff method structures influence inter-port competition and vessel entry decisions plus corresponding freight rates. As shippers increase prices, this influences MSC demand and supply. For the Pacific, any significant port pricing adaptation in response to disruption events may further isolate trade regionally. ADB (2013) and UNCTAD (2014) identify very few international, shipping liner companies with limited competitiveness.

This review's significance identifies that climate change, disruption risks and associated impacts also influence not just ports and shipping firms, but other supply chain stages of producers, transport and distribution. These include road, rail and air intermodal connections, retail and consumers. It influences stages via lost operational, opportunity and business delay impact costs summarised in Table 2.3. (Handfield, Blackhurst and Elkins 2007; US Transportation Research Board 2011; BSR 2014). Each disruption/delay increases associated transport, storage, insurance, labour, port and customs duty, administrative, marketing, information, cargo management, security, insurance and communication impact costs to overall stakeholders. Other indirect costs result from a loss of confidence and reputational costs from customers, who consider that provider less reliable. Australian Institute of Petroleum (2013) provide an example for a fuel supply chain from local supply and import, refinery production, to wholesale bulk fuel terminal storage, transport and distribution, to retail company owned, franchise and independent sites. Upstream influences include domestic and international exploring, production, refining, imports than sale and distribution to retailers. Climate change can therefore cause significant impact costs for stakeholders not just to a supply chain but across the local economic hinterland (Osthorst and Mänz 2012). Long term changes might include economic demand, supply and associated changes in economic activity, employment, production, consumption, exports and imports, inflation and exchange rates. This affects possible purchasing power and trade competitiveness identified in Table 2.4 (Gurning and Cahoon 2011; IAPH 2011; Rozensweig and Horton 2013; Aifadopoulou 2014; Rodill 2015; Newell, Nuttal and Holland 2015). It influences access to maritime finance, insurance premium costs, in global and regional social-political, commercial, environmental instability, along with the changing rate of innovation and technology.

Fewer callers and reduced cargo throughput will create reduced tax revenue for government stakeholders. It reduces potential public budget expenditures and creates indirect opportunity costs to other supply chain stages and levels of economic activity. However, the ultimate economic impact threat climate change poses for MSC stakeholders includes the submergence of substantial sectors of (or entire) Pacific nations and economic markets. This risk is predicted by ADB (2007) and UNCTAD (2014) to affect shipping routes/operations substantially, as this thesis will seek to affirm for a specific Pacific MSC and commodity case study. Based on Kong *et al.* (2013), potential shipping disruption may cause further threats to shipping operations, markets, cargo, sourcing of labour and related productivity. Risks include changes in global and regional, Pacific, social-political, commercial or environmental instability. Communities and stakeholders may become so desperate for survival; they provide a physical health and safety risk to ports, intermodal transport, vessels and crews, in seeking to escape from direct climate change risk impacts. Additional increases in adaptation strategy costs, including those proposed in section 2.6, are further anticipated to reduce commercial viability and sustainability for shipping operations and stakeholders directly.

Examples cited by literature in section 2.6.4 (Rodrigue 2010; MacKinnon, Song and Woolford 2010; Oswald 2011; Meyer *et al.* 2012), include increased staff, disaster response and risk assessment training expenses and improved vessel resilience. It involves updated research, communication and information measures, adapting market and shipping operations to minimise costs from Pacific climate change. Bhaskar, Cahoon and Chen (2014) focus on developing an adaptive cycle for sudden shocks, involving adapting shipping schedules with fewer and smaller vessels, exploiting economies of scale. This could be applied to the Pacific. It points out how shipping companies may have to diversify into new routes or markets, new consumer demand and supplies, diversifying into multimodal transport opportunities, to exploit trade diversion from those failing to adapt and to enhance financial and shipping market resilience.

According to Rossouw and Theron (2009), Finley and Schchard (2011) and Sturgis, Smythe and Tucci (2014), summarised in Table 2.3, labour productivity may further decrease from increased humidity and temperatures, influencing heatwaves and droughts. It presents higher public health and safety impact costs. These may reduce available labour, creating idle capacity from increased employee absenteeism, diminished port performance and other delay costs. Potential adaptation solutions include improved training and adopting flexible working hours such as nocturnal shifts and weekend overtime, midday breaks, protective clothing, equipment and shelter to prevent fatigue. Eco Ltd. (2014) proposes logistics automation for climate change adaptation in Moroccan ports to reduce risk consequences. However, equipment is more susceptible to corrosion and less flexible in adapting. This also imposes additional cost constraints and increases local unemployment and related economic activity. Flooding can influence public health and sanitation through water supply contamination (Zainal *et al.* 2012; Scott *et al.* 2013). It leads to pollution contamination risks from overflowing waste disposal sites, reclaimed/polluted, industrial zone land and insufficiently adapted drainage systems. This affects not just port workers but the surrounding, coastal population, cargo and ecosystems, requiring measures such as greater filters/sedimentation traps.

In developing a theoretical framework to understand and adapt to climate change impacts for MSCs, stakeholders need to consider impacts of previous, current and future changes in legal/technical policy requirements for the maritime and transport sectors. Governments, ports and stakeholder associations are likely to endorse policies as an adaptation solution (Eide and Endresen 2010). These are predicted to provide significant legal, technical and financial compliance costs. This further reduces potential profits amidst other fiscal constraints of conducting business in small Pacific Island economies. The International Centre for Trade and Sustainable Development (2010) reflect that seaborne trade through MSCs offers many economies of scale, weight, volume, time, flexibility, and other advantages compared to alternative road/rail/air transportation. Alternatives are impossible for sovereign nations surrounded by ocean. It is essential for primary MSC stages to respond. It recommends a voluntary, market based, cap and trade emissions system, where all vessels pay a levy and must purchase carbon offset limits. Other options include certain operations and technical measures including eventual ratifying of MARPOL's legislation by all maritime nations.

In reviewing studies (UN Finance Initiative 2006; GICCC 2015; BSR 2015), an existing gap in current insurance and risk management literature comprises increased insurance premium costs, from perceived or actual, risk exposure, liability and vulnerability. This affects carriage of goods by sea, based on risk aversion and asymmetrical information. It touches shipping companies through increased reputational damage costs, unless insurance adapts. This area has yet to receive an official policy or guidelines from global maritime law associations and Admiralty Courts (Agrawala *et al.* 2011), as a potential research area. An additional short-term impact may affect or be influenced by changing technology and innovation. This complicates the decision of which solutions, how, when and where to adapt, that shipping and other Pacific, MSC stakeholders facing significant constraints should endorse to prioritise climate change mitigation or adaptation (Chhetri *et al.* 2015). These risks and short-term impacts may be only partially reduced by increased information, communications, risk management training and investing; supporting research and technology development plus other proposed solutions summarised in this chapter.

Finally; this review advocates the most significant MSC stage affected by risk events and associated impacts includes access to financing and capital investment sectors for climate change adaptation. New production, consumption and investments will be constrained by increasing reluctance by the risk-averse global financial sector to invest in the Pacific based on increased uncertainty, asymmetrical information over potential disruption risks, and sacrificed or delayed profits (PCARFI 2013). This will deny commercial and investment opportunities not only for producers, but shipping companies and other transport distributors, retailers and access to consumer credit for customers. Climate change also threatens insurance companies and financial sector solvency (Schuster 2013) e.g. banking (who may underwrite voyages, cargo, products or other loans to consumers). This influences the capacity for other supply chain stages to transact and perform. This further confounds resilience adaptation strategies (KRQC). These have previously not been implemented across an entire supply chain, to extend beyond just individual ports and shipping.

2.6: CLIMATE CHANGE RESPONSE STRATEGIES

In considering a response to climate change disruption risks to any supply chain stage, it is observed that existing literature has divided into five response strategy themes of mitigation, adaption, retreat, migration or ecological rehabilitation. Existing sources (Bedford and Bedford 2011; ICCAI 2013; SPC 2013; IPCC 2015; SPREP 2015), have proposed these strategies as potential responses. Supply chains concerned with possible consequences could undertake these responses to minimise associated risks and connected impact costs to resources, economies, coasts, infrastructure and populations, as key factors affecting MSC performance. This thesis will identify and analyse specific adaptation strategies for Pacific MSCs in Chapters 7 and 8, to address KRQC. Section 2.6.4 will identify existing literature specific, adaptation measures for ports, shipping and overall supply chain stages.

2.6.1: Mitigation

The more common research trend, identified from several hundred, climate change impact studies, is a focus only on mitigation or reduction of CO_2 emissions as a response to the risks presented by climate change Examples include IAPH (2010), Caballero (2012), Hearn (2012), Business for Social Responsibility (BSR) (2014) and Blanco *et al*. (2014) for the IPCC. To reduce uncertainty, mitigation is standardised and collectively defined by the IPCC (2015), WMO (2015) and UNFCCC (2012) as:

> 'An anthropogenic effort or actual intervention aimed at directly reducing the sources or increasing the sinks of greenhouse gas emissions, and other aspects of climate change to decrease the associated costs, consequences, risks and uncertainty.' (IPCC pg. 129).

In reviewing mitigation literature (Bueno *et al.* 2008; Hazari 2010; Port of Brisbane Authority 2010), supply chain stakeholders which pursue mitigation focus on influencing global climate change causes and the probability or likelihood of a risk occurring. They do not adapt to potential consequences. Mitigation is considered essential by the above sources to stabilise both existing gas concentrations and reduce future emissions levels. This influences the potential rate at which climate change and associated disruption costs/risks occur. Recurrent mitigation studies are evaluated here as deliberate, conscious human efforts to reduce emissions, either through currently speculative, physical measures e.g. geo-engineering, carbon capture and storage technology, or through focussing on reducing actual emissions. This is favoured by an increasing number of supply chain stakeholders (Accenture 2014; CSR 2014; BSR 2015). Potential mitigation solutions identified by literature frequently include restricting emissions through renewable energy, increased infrastructure insulation and energy conservation, fuel efficiency, recycling and waste reduction. Solutions include investment in public awareness, research and technology and afforestation as carbon sequestration sinks, (Scholes, Palm and Hickman 2014; Long and Young 2015; Kagawa *et al*. 2015). IAPH (2013) has already concentrated on recommending similar standardised guidelines for associated port stakeholders to become more environmentally sustainable and reduce emissions through mitigation. As significant global attention has prioritised mitigation over other response strategies, this thesis proposes several reasons for not further contributing to existing, related studies.

Most Pacific small island nations contribute fairly globally insignificant emission quantities. The IPCC (2015) estimate these at 0.03-0.06% of the global total. They therefore incur a comparative disadvantage in surviving. Disadvantages exist in seeking to reduce the potential impact upon MSC stages and coastal communities through mitigation. They are constrained further in possessing a limited capacity to influence global politics to encourage other countries to ratify and enact mitigation policies, being economically, culturally, resource, militarily and politically peripheral from the perspective of developed nations. In contrast, adaptation offers further advantages of being country, economic sector or supply chain stakeholder specific. It is within stakeholders' capacity to directly influence associated risks and specific impact costs, with a tangible, effective response or solution. Only emphasising mitigation also ignores other potential factors that influence the rate of global climate change. Bell, Hume and Hicks (2001) suggest including pollution, human overpopulation and unsustainable development. Mitigation appears reactive. It is based on emissions/risks that have occurred rather than proactive. This would aim at minimising current and future, risks and costs through enhancing key ecosystems, economies and stakeholder resilience. Restricting human attention to prioritising mitigation rather than adaptation solutions that address these factors, is increasingly considered likely to escalate projected uncertainty, business congestion and opportunity costs. Authors e.g. Chhetri *et al.* (2013), indicate this for maritime stakeholders.

Carbon Disclosure Project (2015) contests while emissions mitigation might be necessary, it often incurs significant constraints towards implementing a coordinated global solution, given nations have failed to truly implement the Kyoto Protocol or any intended successors so far. This is supported by an increasing number of research studies (Christensen 2007; World Bank 2012; Matear 2014; Nauru Government 2014), as a reason to favour specific adaptation measures. Therefore, this thesis considers only relying upon mitigation as less efficacious than the alternative of adaptation. This is based on existing nations' slow implementation of the voluntary, self-regulatory cap and trade, emissions market approach, the 1992 Kyoto Protocol and 2012 UNFCCC. This perspective is further measured by increasing emission inventory levels of all nations and supply chains (not just the Pacific), according to IPCC (2015), and subsequent increased threats and cost consequences from more immediate risks to survival as climate change projections in Chapter 4.

2.6.2: Strategic Retreat/Surrender and Migration

Another seldom considered response strategy identified by Gibbs (2013), Cox (2013), Seto *et al.* (2014) and Gadabu (2015) is strategic retreat or surrender. Climate change affected, coastal stakeholders, ports and shipping companies prepare to abandon the most vulnerable coastlines and infrastructure, retreating inland. However, strategic retreat is generally regarded by this thesis as impractical in the absence of a sudden population contraction, whether through warfare, medical contagions, natural disasters or space colonisation. Many Pacific Islands have high population densities and limited land surface areas to retreat, (even less with predicted increases in sea level rise). Given budget constraints of governments, Gibbs (2013) considers the significant sunk costs of existing coastal infrastructure as another further constraint to strategic retreat. An alternative is migration, researched by Kelman (2010) for the Caribbean and a limited sample of 22 emigrants from Funafuti, Tuvalu by Mortreaux and Barnett (2009). Yet migration is often subject to issues i.e. immigration border controls, loyalty to home, family, economic, social, political, cultural and personal pressures hindering mobility. Climate change as a genuine threat for refugee status was rejected as a non-immediate and indirect threat by the New Zealand government in a 2015 court case; (UNISDR 2015). This provides legal uncertainty for Pacific nations in retreating and migrating as a viable alternative.

2.6.3: Ecological Rehabilitation

This section identifies ecological rehabilitation as a fourth response strategy in existing research sources. This thesis, noting the absence of a formal definition to describe this process, proposes ecological rehabilitation to describe an intentional effort of restoring, renewing and acclimatising degraded, damaged or disturbed natural ecosystems of ports, coastal communities, populations, economies and associated MSCs. This includes mitigation, physical repair and eventual adaptation to as close to their original state and capacity, as practically possible. Mimura (1999) initially proposed ecological rehabilitation as an alternative, response strategy with a community participatory approach based on simplicity, sound environmental management and indigenous, stakeholder solutions. This is seldom cited by climate change impact studies, from stakeholders favouring alternatives to adaptation and mitigation, (Savonis, Meyers and Potter 2012; Sawyer 2014; Tyndall Centre for Climate Change Research 2014).

Despite significant ecological damage reducing its current effectiveness, this natural coastal protection method pre-dates the origin of humanity. Lorde *et al.* (2013), evaluates the economic and social effects of coastal based, climate change for the Caribbean maritime economy. It is one of the few identified sources that considers Earth provides natural resilience and protection, stabilising ports, ecosystems and the maritime sector. Pezzoli *et al.* (2013) develops this further for Brazil based areas. Ellison (2014), emphasises mangroves' roles not just in biodiversity and habitat formation but in coastal protection from climate-related events (including natural disasters), from inundation and excess salinity, filtering pollution, carbon and coral reef health. Ecological solutions combined with an internationally implemented, joint committed response to adaptation can further provide natural protection for coastal assets, ecosystems and communities, reducing exposure and sensitivity. It also aids a natural resilience approach against subsequent potential ecosystem and supply chain productivity losses, from physically exposed coastal assets. An ecological approach was also considered by Keener *et al.* (2013) for reducing disruption costs for vulnerable Pacific, maritime economies and supply chains, with significant fiscal, technology, time and education constraints.

The ocean and coastal atmosphere/ecosystem serve a specific role in preserving, environmental and economic stability, enabling all life to survive. An indigenous, Pacific approach of natural engineering/ ecological rehabilitation is particularly efficacious at enhancing resilience. World Wildlife Fund (2003), Nature Conservancy (2004) and Ratukalou and Alefaio (2013) favour utilising the environment to provide natural barriers and resilience to climate change. This is considered a more cost-effective and climate resilient solution than physical infrastructure, engineering solutions or only a simple emissions mitigation suggested by Australian Shipowner's Association (2005), Wunder (2011) and Hiranandani (2012). However, ecological rehabilitation is a long-term, though necessary process. It provides significant environment co-benefits of resource, coast and infrastructure protection. For this thesis, adaptation is applicable to many supply chain stakeholders potentially affected by climate change. It provides a more focused, short term attempt for Pacific nations to pursue in reducing specific disruption costs. This study therefore represents an improvement upon those climate change, impact studies for supply chains (Forfas 2010; CSR 2011; BSR 2014; Samples, Riseng and Diana 2014). These have ignored the protection of coasts, infrastructure and seaborne trade Earth provided against natural disasters when proposing adaptation solutions.

2.6.4: Adaptation

This section focuses on another identified, literature response strategy of adaptation, a solution less often considered than mitigation. This solution, mentioned by the University of the South Pacific (USP 2013) and the Australian Department of Climate Change (2010), is defined by this thesis from these sources as:

> ‘The physical process of deliberate actions and efforts adjusting, acclimatising, adapting and responding to actual or expected changes in climate/environmental conditions on natural or human systems, infrastructure and/or beings, with the intention or aim of moderating or avoiding externality/opportunity costs or exploiting beneficial opportunities occurring as a consequence of that change.’

Conceptually consistent definitions of adaptation can reduce risks of climate change maladaptation costs. It can assess the extent to which specific measures achieve adaptation, given literature from Caldwell *et al.* (2003) and Wardekker (2011) to Averchinkova (2015) all present diverse adaptation solutions. The advantages of adaptation and ecological rehabilitation over alternative approaches is that they aim to increase a port, shipping or other MSC stages’ resilience to physical risks (Osthorst and Mänz 2012; Messner *et al.* 2013; Filosa and Oster 2015). This thesis agrees with the above sources and SPREP who consistently define Resilience as:

> ‘The capacity of social, economic and environmental systems to cope with a hazardous event, trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity and structure, while also maintaining the capacity for adaptation, learning and transformation.’ (SPREP 2012 p.4)

Defining resilience enables affected stakeholders to have a standardised basis to evaluate adaptation solutions’ effectiveness. Additional advantages of prioritising a resilience adaptation strategy are considered by Benjamin (2010) and Scott *et al.* (2013). Primarily it allows forewarning and preparation to ensure continuity (or at least survival) of human economic, social and other activities at minimal disruption costs. These aim to reduce the extent to which it could threaten the survival of small islands and vulnerable coastal sectors, infrastructure and economies. This is crucial, given dependency on one or a few commodities providing a significant contribution to GDP and exports.

2.6.4.1: Climate Change Adaptation Measures and Strategies for Ports, Shipping and MSCs

To further address KRQC, this section summarises and evaluates various specific adaptation measures implemented by ports and shipping in Table 2.4. These include increased environmental sustainability, rehabilitation and emission reduction. Examples include relocation, elevation, increasing inter-modalism, changed legal preparations, product operations, resource input sourcing, marketing and routes. In response to climate change impacts across MSC systems, stages and stakeholders, this thesis agrees with emergent sources e.g. IAPH (2011), Naruse (2011) and Wang (2015). These increasingly focus on needing stakeholder coordination in information gathering, early warning systems, communication, planning, risk-vulnerability assessment and management, emergency disaster response training and education. Stakeholders must adapt across a supply chain. Martinez *et al.* (2011) identifies investing in new technology, equipment and infrastructure or modifying current processes. Stakeholders need to respond to changes in government or other authority tax, legal regulatory and other policy requirements. These proposed solutions are technically feasible, cost-effective and globally applicable, given developing country constraints e.g. those of the Pacific. This is advised by Scott *et al.* (2013), McNamara, Hemstock and Holland (2013) and New Jersey Climate Adaptation Alliance (2014). Given climate change, scenario assumptions (IPCC 2015) and specific Chapter 4 projections, this review considers supply chain stages should consider adapting as soon as possible to minimise risk. These strategies could be endorsed by stakeholders as coordinated strategies in Table 2.5. This minimises previously identified risks and associated impact costs.

Potential adaptation solutions to flooding port areas from SLR and increased precipitation are proposed in Table 2.4 (Anthoff *et al.* 2011; Karambas 2011; Messner *et al.* 2013). This table was devised by a combination of candidate innovations and existing Chapter 2 identified sources. Solutions include strategic retreat or surrender, physical elevation of facilities and land reclamation (McMillan, Jackson and Poyck 2010); McLaughlin, Murrell and DesRoches 2011; McEvoy *et al.* 2013). However, many Pacific territories face high population densities with limited land area and financial resources to strategically retreat or to relocate populations, ports and associated MSCs/economies with high fixed capital costs (Petrini 2015). These constraints, combined with geographical constraints that Pacific nations including Micronesia, the Marshall Islands and Niue are only a few metres above sea level at highest altitudes and are based on weak soil foundations, undermine attempts to elevate many structures. Repeated event intensity and duration corrode attempts at progressive dredging and land reclamation. To adapt, this thesis points out the benefits of essential facility elevation wherever possible. This especially applies to pumps, generators, computers, records, other equipment and technology needed to retain port functions and emergency responses, when adjusting to risk events and associated impacts.

Physical engineering adaptation strategies such as levees, dykes and storm retention basins have been proposed by Becker *et al.* (2011). This uses the example of 2004 Niue's Cyclone Heta, where storm surge waves exceeded 30 metres, to point out these measures' advantages for international port administrators against flooding and wave damage impacts. Without existing seawalls, related disruption cost would have been far higher. Frequent anticipated and current Pacific risk exposure provides a progressive weakening of structural resilience over time. Increased dredging may assist for beach nourishment, crops, construction and land reclamation of submerged port areas. Chhetri *et al.* (2013) recommends port equipment, e.g. shore cranes exposed to storm surge, tidal change and flash floods/tsunamis, precipitation and wind within the port and adjacent roads/rail, will need relocation, revised maintenance or adaptation. They propose adapted training, flexible working hours, new equipment and new technology e.g. Container Terminal Operations Simulator software. This is capable of assessing the impact of changing climate variables and related average productivity loss for port assets and operations.

However, these port adaptation measures summarised in Table 2.4, provide certain disadvantages for Pacific nations. They are expensive to construct and inflexible to sheltering ports against repeated risk exposure from sudden disasters. Abel (2011) in advocating coastal zone protection via strategic development retreat and Monnereau and Abraham (2013) for Kosrae Micronesia; discourage these measures as weakening natural resilience. These measures contribute to coastal erosion, disturbing ecosystems and species habitat degradation. Excess storm runoff still presents a flood risk.

Table 2.4: Climate Change Risks, Impacts and Specific Adaptation Measures for Ports and Shipping

<table>
<tr><th>Risk Events</th><th>Long- and Short-Term Impacts</th><th>Proposed Adaptation Measures for Ports</th><th>Proposed Adaptation Measures for Shipping</th></tr>
<tr><td>Long Term Risks</td><td>Table 2.2</td><td>-Observatories and early warning systems.
-Changes in technology, infrastructure design, technical standards, research and development.</td><td>Changes in routes, markets vessel design and technology, vessel pricing, marketing, research and development</td></tr>
<tr><td>Short Term, Sudden Risks
Storms/Superstorm</td><td rowspan="3">Table 2.3

-Physical vessel/port/commodity damage.
-Higher insurance premium, repair, maintenance, labour, voyage, charter and other costs,
-Reduced port access, increased congestion, physical navigation risk
-Threats to vessel navigation, safety, delays and congestion.
-Changes in demand, supply, port profitability and pricing
-Changes in routes, markets, trade diversion and reduction,
-Reputational loss impact
-Physical legal and technical regulatory compliance costs, increased insurance liability costs
-Operational/financial cost loss
-Planning, preparation or adaptation cost in devising solutions</td><td>-Observatories and early warning systems
-Acquire new/upgraded port equipment
-Natural Engineering
-Climateproofing infrastructure, drainage Facility relocation, elevation, strategic retreat and land reclamation.</td><td>-Increased risk awareness assessment, monitoring, stakeholder education and training
-Vessel engineering strengthening and redesign</td></tr>
<tr><td>Hurricanes, Cyclones, Tsunamis</td><td>-Critical port functions can face relocation, elevation or retreat inland
-Physical Engineering levees, dykes, storm retention basins
-Increased coastal vegetation zones and legal foreshore protection to reduce surface moisture/coastal erosion.
-Redesigned water storage, drainage and infrastructure for greater protection.
-Increased rainwater storage/improved drainage to reduce port area runoff</td><td>-Meteorological Stations, satellites and other early warning systems plus coordinated port stakeholder information, communication and training</td></tr>
<tr><td>Heatwaves</td><td>-Natural Engineering/ecological rehabilitation e.g. mangroves, afforestation, beach nourishment and coral reef restoration
-Revised engineering designs, standards and technological adaptation
-Anti-corrosion paint plus concrete additives, climate-proofing infrastructure
-Port Pricing Changes</td><td>-Flexible working hours, shade, adjusted training, protective clothing/improved facility insulation and new equipment.
-Improved cargo insulation, Renewable, sustainable energy powering emergency reefer points</td></tr>
</table>

Droughts		-Excess precipitation storage/ attenuation systems and water conservation and diversion plus efficiency measures e.g. education and conservation policy legislation, training -Increased monitoring/information sharing -Provide greater worker and equipment protection, improved training, flexible working hours and nocturnal shifts to prevent supply chain disruption costs. -Improve cargo throughput protection by reducing exposure, enhancing facility insulation and protection. -Greater information and communications updated periodically to reassure stakeholders.	-Wind breaks, -Physical engineering research and redesign standards, --Facility relocation. -Mangroves/afforestation for natural protection -Adjust training, -Increased current monitoring systems -Short term intermodal transport shift.
Landslides		Provide emergency planning response training and equipment -Modify potential building/other code zones to reduce the threat of erosion on potential destabilised slopes. -Plant slope vegetation to increase evaporation and transpiration -Ensure sufficient waste locations and design standards are in place.	-Not applicable –except as landside cargo, infrastructure and cargo are affected in higher delay/opportunity, fiscal costs.

Source: Author.

Aesthetically, coastal engineering adaptation measures, increased coral reef bleaching, ocean acidification and precipitation also discourage fishing, beach tourists and cruise passenger visits, reducing related commercial and port revenue. Global and Pacific port stakeholders possess alternative climate change adaptation solutions starting to be investigated and increasingly prioritised, (Meersman, Van-de-Voorde and Vanelslander 2009; Port of San Diego 2013; Northeast Shipping Management Company 2014). Examples include revising technical standards, continuously updating existing and future port designs to consider climate change and investing in equipment and technology. It extends to improving disaster–emergency, risk management training and preparation. In addition, adaptation may require modifying port pricing policies and enforcing legislation to adjust to foreseen risks.

Other climate change adaptation solutions include natural engineering, with increased coastal vegetation zones, beach re-nourishment, mangrove afforestation, siltation traps and urban planning controls through legal foreshore protection. These are recommended by academic and port authorities e.g. Albert *et al* (2010) and Rao *et al.* (2013) and summarised in Table 2.4. These measures reduce surface moisture runoff and coastal erosion, with minimal adaptation cost and resources required. Potential climate change impacts on Pacific ports include environmental costs identified in previous research e.g. Boesch, Field and Scavia (2000). Examples include losses to ecosystems, biodiversity, reduced mangrove, coral reef and wetland shelters and an increased threat of overflowing pollution. This threatens natural coastal protection from SLR, increased ocean acidification, CO_2 concentration, pollution and sediment. Altered water supply from changes in precipitation affects port bunkerage, cleaning and other services. These risks spread when considering existing factors promoting vulnerability, including a port and supply chain's physical topography, land use, population density, natural resource endowment and extent of remaining vegetation. These risks further influence a port and coastal community's climate resilience, probability of survival and adaptation. This is emphasised by Lorde *et al.* (2013) for its similarly affected Caribbean, maritime economy sector. Table 2.3 outlines ecological rehabilitation as a potent adaptation solution. Coastal buffer zones of mangroves, afforestation, seagrass, algae, marine ecosystems and coral reef restoration increase resilience.

This review proposes climate-proofing of physical infrastructure. It also favours the natural engineering approach of planting mangroves, expanding coastal vegetation, stabilizing coastal beaches and improving coral reef health to enhance innate natural resilience. These provide the same benefits for risk changes across time for small Pacific nation examples as for densely populated ports of Australia. These ecosystems have historically protected ports, coasts and communities, whilst heightening vulnerability when removed. This is evident for the coastal protection, case studies by Government of Kiribati (2009), Peinhardt (2014) for Kenya and the Maldives and Paeniu *et al.* (2015) for the Pacific. Increased soil moisture from precipitation, storms, tsunamis and cyclones can destabilise road, rail and coastal erosion, creating congestion delays from debris and destroyed infrastructure, (World Bank 2012; SPC 2013; IPCC 2015). They are highly cost-effective to construct with minimal need for skilled labour, technology, education, training and other resources. In proposing specific, Pacific adaptation measures, it added 37,000 mangroves in Tarawa Kiribati. These provide natural wind breaks and coastal vegetation to absorb surplus precipitation runoff in addition to sea walls. Related legal/policy adaptation responses to minimise associated erosion costs include an integrated, coastal management approach with increased coastal reserves, improved foreshore protection, environmental impact assessment legislation, land use and building code zoning. It extends to revised engineering and technical framework strategies (New Zealand NIWA *et al.* 2012). Another projected impact includes increased insurance risk premium costs. This arises from a growth in projected risk and uncertainty over climate change. (World Bank 2001). To assist Pacific stakeholders to adjust coastal developments, the World Bank (2013) propose a pilot scheme for climate risk-based insurance. This is conditional on enhancing natural, coastal and infrastructure protection and resilience; reducing potential asset exposure.

These adaptation measures have time and fiscal advantages for Pacific nations with significant technical, skilled labour, port equipment, financial and other constraints. They can adjust solutions to current and future supply chain infrastructure, equipment, training and cargo to minimise potential disruption risk costs from risk events. Other adaptation measures that apply to ports, shipping and overall MSCs include increased risk awareness assessment. Joint risk adaptation solutions are increasingly favoured by those such as Steffen, Hunter and Hughes (2014). Examples include improved meteorological stations, weather monitoring, observatories and early warning systems to anticipate disruption risks and prepare with as much time and information as possible. Investing in stakeholder education and training allows time and flexibility to adjust to risks. This provides pre-emptive adaptation strategies (ADB 2006; Boyle, Cunningham and Dekins 2013; Port of San Diego (2013). This thesis's contribution to existing literature gaps will be to identify, adapt and evaluate these measures to address systematic risk. It establishes specific adaptation strategies for supply chain stakeholders and stages in Chapters 7 and 8. These are summarised in Table 2.5 for previously identified risks and associated impact costs.

Increased global supply chain, stakeholder cooperation and coordination in information gathering, early warning systems, communication, research and planning are recommended in Table 2.5. This table was devised by combining Tables 2.2/2.3, candidate ideas and existing Chapter 2 identified sources. Naruse (2011), Brooks *et al.* (2012) and Ng, Cahoon and Chen (2014), identify multiple examples of cooperation benefits to lessen risks and impact costs. Examples include economies of scale, avoiding wasteful duplication of unnecessary resources, increased efficiency and supply chain performance. Potential congestion, reputational, business delay, economic, environmental and other opportunity costs are lowered. This thesis provides adaptation strategies considering the limited labour, technology, budget, land, infrastructure and institutional governance capacity, constraints of Pacific nations; (Bell, Johnson and Hobday 2011; SPREP 2014; Kumar and Taylor 2015). Whether climate change will permit a sustainable future for affected stakeholders depends on the extent to which they prioritise strategies summarised in Table 2.5.

Numerous research sources ignore or underestimate the disruption impacts climate change initiates on MSC stakeholders with limited resources, in proposing expensive climate-proofing solutions, especially those of the Pacific e.g. Garcia and Papi (2015). Developed World literature including UNCTAD (2011), Becker *et al.* (2013) and Van-de-Meer (2011) for Rotterdam, largely ignore these factors. They propose resource, capital, technology, skilled labour, education and wealth intensive solutions, e.g. hard and coastal engineering approaches, as common resilience strategies. Conversely, Becker *et al.* (2011) points out just how few existing sample surveys have been done for maritime stakeholder awareness and adaptation to climate change. UN Economic Commission for Europe (2014) focus on technology, specialisation, globalisation and economies of scale but not on sustainable development or resilience of international transport network adaptation. It ignores climate change. Yet research gaps occur from ignoring the significant costs of paralysing economic activity globally from MSC failures. Accenture (2014) considered mutual cooperation in risk education, information, existing technology and policies alone could simultaneously reduce over $2 trillion worth of economic disruption costs to global supply chains. This enhances resilience of global ecosystems and MSCs simultaneously. Directly or indirectly, climate change will affect every port, commodity, MSC, connecting economic hinterland and dependent stakeholder, via sea level and temperature rise to varying extents (Becker *et al.* 2013; WTO and UNEP 2009). Fairhurst (2008) recommends further key stakeholder interaction and using GIS satellite imagery to graphically emphasise climate change's devastation costs are not just gradual.

Table 2.5: Summary of Hypothetical Climate Change Risks, Impact Costs and Adaptation Strategies for MSCs

General Risks	Climate Change Disruption Impacts for Supply Chains	Proposed Adaptation Strategies
Long Tern Risks Table 2.2	Increasing of greenhouse gas emissions/ climate change	Pre-emptive via mitigation, retreat/surrender, migration, Reactive –ecological rehabilitation
Long Term Climate Change Risks/ Associated Impact Costs Short Term and Sudden Climate Change Risks/ Associated Impact Costs Table 2.3	Physical vessel/port/commodity and infrastructure damage.	-Increasing vessel, equipment, infrastructure and operational resilience/training to minimise disruption threat costs. -A short term transport intermodal shift from road/rail to less affected shipping/air for vital cargo may occur Physical engineering Natural engineering
	Higher insurance premium, repair, maintenance, labour, voyage, charter and other costs, reduced port access, increased congestion, physical navigation risk	-Adapting through increased disaster risk response, information gathering and early warning systems -Improved training, disaster emergency contingency planning and vulnerability risk management adaptation, physical adaptation of vessels
	Threats to vessel navigation, safety, delays and congestion.	Greater coastal reserves, adjusted courses, modified legislation, slow steaming
	Changes in demand, supply, port profitability and pricing, commodities and input sourcing	-Increasing market flexibility to favour smaller vessels/lobby for reduced port rates during disasters based on remote Pacific locations/increasing other inter-port competitiveness. -Consumers and producers may alter preferences
	Changes in routes, markets, trade diversion and reduction,	Flexible marketing, delivery arrangements and adaptation with smaller/fewer vessels, short term intermodal transport shift to less physically exposed alternatives
	Reputational loss	Improved and coordinated information/ communication, increased security and resilience training/disaster management -Prioritise mitigation/environmental adaptation solutions
	Physical legal and technical regulatory compliance costs, increased insurance liability costs	Increased access to political-legal information and participation through offering stakeholder advice/lobbying, to minimise uncertainty
	Operational/financial cost loss	Improved and coordinated information/communication to prioritise climate change awareness and risk management
	Planning, preparation or adaptation cost in devising solutions	Increasing support for research and technology endorsing solutions

Source: Author

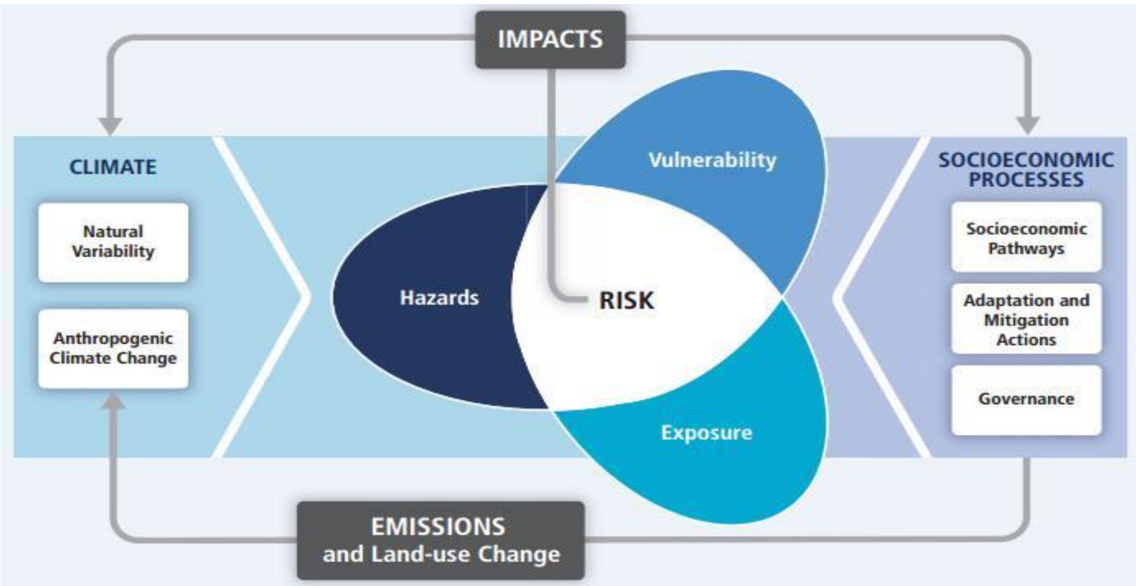
Jansen (2013) also focuses on three future options for the global transport system facing global warming, retaining pure economic growth as the first alternative. The second includes seeking new eco-efficiency, climate mitigation, investment in research and technology via a low growth, selective development response. This favours the environment using strategic retreat, ecological rehabilitation and requiring more eco-conscious efforts. The third option alternatively responds through physical engineering adaptation techniques and demand reduction management, which will affect various international MSC stakeholders. Although most ports, especially in the Pacific, lack the extreme solution of physical relocation of entire supply chains, certain developed ports such as Rotterdam (Van-de-Meer 2011) have increasingly favoured this approach. Australia and New Zealand at least have the expensive possibility, opportunity and capacity of all Pacific nations of diverting more activities to inland dry ports, less exposed to coastal, climate consequences. As more coast is exposed in Australia and New Zealand, more cargo may have to be redirected towards inland nodes causing additional road/rail congestion, maintenance and urban infrastructure pressure. However, this thesis notes dry ports are not a feasible substitute, as the other 14 Pacific nations lack resources and geographical locations. Many are predicted to significantly or entirely disappear in land surface area.

Fenton (2014) focuses on the implications of port cities in response to climate change adaptation, extending it beyond the port authority alone, as in Becker *et al.* (2013). It endorses establishing a transnational, municipal network of port cities and supply chains. It points out the free-rider risk problem many will face in persuading others to join this network. Certain stakeholders desire others to finance adaptation instead. It further endorses a cooperative approach, so ports can enact climate risk evaluation, mitigation and adaptation strategies without losing their inter-port competitive advantage status. It once more primarily focuses on mitigating CO_2 port and vessel emissions. This ignores other significant contributing factors towards global warming and the need for diverse and more successful solutions to implement. This research favours the need to minimise disruption costs via the alternative of active stakeholder adaptation (KRQC). The weakness of many adaption scenarios noted by BSR (2011) for engaging Asian business stakeholders is that most contingency planning efforts are isolated not coordinated. They exclude Pacific nations from direct formation and participation. This presents significant risks in response value. It misdirects priorities and wastes scarce resources, given Pacific constraints.

This review advocates effective adaptation strategies consist not only of minimising adverse consequences but exploiting any potential benefits such as additional commercial opportunities that climate change may necessitate for Pacific and global MSCs. Opportunities include trade diversion from less climate resilient MSC stages. It incorporates outlasting competitors failing to adjust, as identified by Becker *et al.* (2011). Despite this heightened risk exposure, that sources from the Australian Academy of Technological Sciences and Engineering (2008), Murray (2010), Daskillis and Pappis (2013) to this thesis seeks to affirm, people seem reluctant to truly prioritise climate change and to pay the initial sacrificial cost. This is reflected in increasing gas levels, temperature and SLR described in Chapter 4.

This chapter agrees with Maddox Consultants (2012). Adaptation strategies provide an anticipation and behavioural adaptation to psychologically and physically acclimatise over time to long- and short-term risk events, pressures, impact costs, constraints, challenge, and consequences. This entails higher anticipated adjustment costs to be effective; rather than just a reaction approach to events. Without considering mitigation, retreat, ecological rehabilitation and adaptation strategies as potential responses, risks appear increasingly unavoidable. In conclusion, an effective risk assessment framework for Pacific MSCs would integrate mitigation, adaptation, retreat/surrender, relocation, governance and policy issues and ecological rehabilitation, as illustrated in Figure 2.2 where the risks and adaptation measures would be as summarised in Tables 2.4 and 2.5. Risk is further developed through Chapter 5 and impacts via specific MSC stage costs in Chapter 6.

Figure 2.2: Risk Assessment Framework



Source: IPCC 2015 pg.7.

2.7: IDENTIFYING EXISTING LITERATURE GAPS AND THESIS CONTRIBUTIONS: THE FURTHER NEED FOR AN INTEGRATED SUPPLY CHAIN SOLUTION.

In summary the key research gaps identified, some of which this study will aim to address, include:

- The risks and impact of climate change on specific Pacific ports.
- The unique impacts, risks and solutions for shipping and MSCs.
- The impacts on customs, access to maritime finance, and port pricing.
- The need for and impact of changes in legislation and policies.
- The implications of species migration and biodiversity changes for shipping routes, coastal areas and ports.

These gaps justify its research significance and establish the further need for an integrated, adaptation solution for supply chain stakeholders. This is motivated for the following reasons. Although other regions including the Caribbean (Tetra-Tech 2014) and developing economies and supply chains have been researched, a systematic literature evaluation failed to locate a study specifically concentrating on the risks and impact of climate change on any Pacific port, shipping and MSC; nor for any specific commodity. This research remains highly necessary. Past literature identifies nations and MSCs face individually unique impacts, climates, risks, costs, consequences, benefits, constraints to implementing solutions and adaptation solutions (Pauli *et al.* 2010; Dasaklis and Pappis 2013; Jira and Toffel 2013). Sources seldom consider potential similarities and differences in these impacts, risks and solutions, (E.g. Maunsell 2008; Australian Government Department of Infrastructure and Regional Development 2014; New Zealand Ministry for the Environment 2005). Existing themed literature ignores the complexities of climate change interactions and disruptions; particularly to an entire MSC. Examples include Baker and Week (2013) on Pacific infrastructure and climate change resilience and Kong *et al*. (2013) for core port infrastructure structural resilience but ignore other supply chain stages. Customs, access to maritime finance, changes in port pricing and legislation have been ignored by other studies as substantial literature gaps. This thesis also represents the first case study on Pacific supply chains and MSCs.

Few literature sources are starting to prioritise possible implications of climate change on global supply chains, (e.g. Khosa 2013 for the UK and Laderach 2011 for coffee). This study seeks to distinguish itself by establishing whether similar risks, impact costs and adaptation solutions are specifically applicable to the Pacific. Although certain developed country examples have been examined (Dolfman, Wasser and Bergman 2007 for Hurricane Katrina, New Orleans and Dircke; Wijsman and Molenaar 2014 for Rotterdam); this thesis concentrates on the Pacific for several reasons. For the case study examples investigated in Chapters 5- 7, the supply chains consist of simple commodities, a simplified port authority, government, customs processes with few stages and stakeholders. This assists to more accurately assess potential risks, impact costs, and adaptation solutions. In surveying Pacific reports (ADB 2014; SPC 2014; SPREP 2015), each selected nation consists of a simple economy and small land mass. Economies are dominated by a few basic imports/exports, especially sensitive to climate change such as aquaculture, agriculture and mining e.g. seafood, coconuts and timber. Trade is primarily seaborne for each Pacific nation according to UNCTAD (2014) Limited or no road, rail and air transport substitutes exist, dominated by the capital main port. This simplifies isolating the economic impact of climate change for MSCs.

This thesis is motivated from an observed trend of ever increasing risks and associated impact costs for Pacific MSC stakeholders. This research's significance partially derives from sources e.g. UNESCAP (2015) and UNISDR (2015). These provide an account of how many lives, how much economic, environmental and social disruption has been wrought by ignoring the increased frequency and duration of related events, especially to supply chains. Existing climate change reviews have primarily concentrated on the Pacific's historic and existing, natural constraints and climate for economies and ecosystems, via sudden impacts of natural disasters. This was previously reflected in the introduction. For example, Cyclone Ian in 2014 cost an estimated US$48 million in direct physical damage in Tonga (Guha-Sapir, Below and Hoyois 2015). Wind velocity up to 200 kph damaged 85% of water and 90% of electricity distribution networks. In 2014 Cyclone Ita created 40 deaths and over $1.15 billion in direct damage to agriculture, transport, property and the economies of Papua New Guinea, Solomon Islands, Queensland Australia and New Zealand. In December 2014, Fiji experienced severe flooding disruption costs from over 280 mm of rain in 24 hours. One IPCC (2015) projection is the intensity and frequency of these events will only increase from climate change. This literature review is highly relevant to the present. It emphasizes just how vulnerable Pacific regional supply chains are to risks.

Pacific countries according to Gero *et al.* (2013) are far more economically dependent on their capital than developed countries with multiple ports e.g. the United Kingdom, France, Germany, Italy and the United States. Pacific shipping already suffers from technologically obsolete vessels, scattered markets/communities, few resources and vulnerable infrastructure and ports. Fuel costs occupy a significant percentage of cargo imports (Allison *et al.* 2009). Pacific climate change offers potential to physically destroy the majority of a commodity's supply chain including its resource and labour inputs, seaports and economy. As identified as early as SPREP (1999) and by Tavaga (2006) for Fiji, these Pacific nations face fewer choices than more developed nations, experiencing perhaps greater risk, vulnerability, costs and uncertainty. Pacific economies are generally highly reliant on the ocean sector for maritime transport and supply chains, from point of origin/production to point of consumption, and climate for survival. MSCs dominated by primary commodities experience already limited shipping markets, domestic market demand and high reliance on exports/imports, high refuelling, repositioning costs and other constraints identified by Scott, McEvoy and Chhetri (2013). Reports such as Faavae (2007 for Tuvalu) and Keener *et al.* (2013) generally, identify significant economic development and environmental pressures. These include water and air quality, waste disposal, noise, habitat conservation, energy consumption, oil spills, resource conservation, dust and vessel emissions. These pressures exist; apart from geographic isolation and high transport costs discouraging economies of scale in the Pacific.

This utilises research advantages of Pacific developing states as MSC case studies. These advantages include extensive historic experience and risk exposure to natural disasters and adaptation strategies plus access to specific NGO and government funding. Unlike many other nations, they are preparing to survive. Previous studies have separately concentrated on risk-vulnerability and impact costs with proposed adaptation solutions, this thesis aims to be the first to provide a coordinated research methodology and solution. Stakeholders may lack the conceptual framework of understanding and information to ascertain the extent to which climate change can disrupt each potential stage. It establishes the significance of potential, maritime risks and impact costs. Increasing globalisation significantly multiplies risk and vulnerability for individual stakeholders and across supply chains. Impacts surveyed in established literature urge stakeholders consider these risks as a physical indicator of the urgent need to act. Stakeholders need to adapt swiftly to minimise related externality/opportunity costs. This review considers being essentially reactive to events rather than proactive in adaptation will significantly increase further disruption risks to global supply chains, ecosystems and communities.

CHAPTER 3 RESEARCH METHODOLOGY

3.1: INTRODUCTION

Based on Chapter 2's review of literature strengths and gaps, this chapter establishes a research methodology and strategy. It identifies and evaluate climate change, disruption risks, economic impact costs, adaptation constraints and strategies for a specific commodity. It proposes its integrated, conceptual and analytical framework method for key Pacific, maritime supply chain (MSC) stakeholders to more efficiently analyse, evaluate and prioritise risks. This method determines climate change's significance in impact cost magnitudes. It considers which adaptation strategies to endorse in results chapters 5-7. This aims to assist stakeholders to minimise associated disruption costs to each supply chain stage and across an entire system.

To develop this methodology, existing relevant method approaches are reviewed. These target climate change, risk management, overall economies and supply chains (in stages) separately. Methods include qualitative and quantitative, (both simulation/mathematical modelling and other econometric approaches). Chapter 2 confirmed no consistent, literature recommended, research design and method exist for stakeholders. Hence, a theoretical/conceptual framework is proposed to help identify research variables, relationships and their methods for MSCs. This addresses KRQA-KRQC. This thesis's theory contribution proposes modifying methods in a research design, combining all three approaches. The conceptual framework is then applied to develop an integrated, analytical framework, including data collection and analysis methods.

Section 3.3 proposes a conceptual framework to identify climate change risks for Pacific MSCs based on risk projections in Chapter 4. It develops a vulnerability-risk assessment sequence. It forms a combined probability distribution and risk event-impact tree method. Its thesis conceptual contribution identifies and evaluates historic and future, risk event probabilities. Section 3.4 presents the research design. This includes the survey question design, ethics application, sampling and data storage/collection process. Section 3.5 presents the analytical method used to evaluate impact costs to MSCs, with model assumptions and limits. The proposed multistage, research strategy includes an interview/survey primary data collection Stage I, (section 3.4) to address KRQ's. It outlines questions, specific Pacific research locations and economically strategic commodities for Chapters 5-7. Stage I aims to ascertain stakeholder awareness of consequences. Stage II summarises the risk-vulnerability sequence. Stage III outlines the impact cost analysis.

Stage IV proposes adaptation constraints, strategies and the extent to which it has been successfully implemented in Section 3.6. Section 3.7 is the chapter summary and conclusions.

3.2: EXISTING APPROACHES TO CLIMATE CHANGE AND RISK RESEARCH FOR MSCS.

This section provides an overview of existing method approaches on climate change and risk research, applied to MSCs by this thesis. A search of supply chain/risk management studies is first conducted using various keywords including 'climate change adaptation/impact', 'risk management,' 'economic impact' and 'ports/shipping/transport/supply chains.' The search also checked various databases including SCOPUS, Web of Science, Google Scholar and Academia.edu. These were continuously updated, as relevant studies were located. The search found no specific searches related to climate change, risk management and MSCs or Pacific MSCs. From 912 sources reviewed from UNFCCC (1999) to Bojinski *et al.* (2014), only 27 provided possibly relevant, quantitative and qualitative methods to evaluate. Reviewing methodology literature confirmed researchers proposed methods i.e. Caldwell (2003), Nursery-Bray (2009), Simpson *et al.* (2010) and USP (2013c). However, they failed to provide empirical case studies. Pinto, Kay and Travers (2008) identified over 200 variations on climate change risk, impact and adaptation method approaches, without providing results to validate them.

Although many methods appear to exist, most are variations of very few models sharing similar characteristics. Method models can be divided into three groups: qualitative (section 3.2.1), model simulations (3.2.2) and others (econometric, probabilistic and non-mathematical model, methods (section 3.2.3). These methods will be defined in following sections. Method characteristics will be outlined and applied to existing climate change/risk management research. The implications for maritime/general supply chains are specifically connected. Significant established method advantages and disadvantages are also analysed. Section 3.2.4 summarises method findings. It evaluates how these methods and Poisson distribution are specifically adjusted over others. This aims to overcome existing risk management method gaps for Pacific MSCs. This is specifically applied to this thesis's key research objectives. It proposes a new integrated method, to aid stakeholders seeking a consistent method when prioritising these risks. This forms the basis of the theory, analytical framework and sequence, proposed in sections 3.3/3.5.

3.2.1: Qualitative Methods

Although existing sources fail to provide a consistent definition or description, the majority define qualitative research methods as similar to the following NHMRC (National Health Medical Research Council (2015) definition:

> 'Qualitative research involves disciplined inquiry that examines people's lives, experiences and behaviours, and the stories and meanings individuals ascribe to them. It can also investigate organisational functioning, relationships between individuals and groups, and social environments. This research approach can involve the studied use and collection of a variety of empirical materials including case studies, personal experience, life stories, interviews, observations, and cultural texts.'

Australian Survey Research (2017) define it online as:

> 'Qualitative research is aimed at gaining a deep understanding of a specific organization or event, rather than a surface description of a large sample of a population. It aims to provide an explicit rendering of the structure, order, and broad patterns found among a group of participants. It does not introduce treatments or manipulate variables or impose the researcher's operational definitions of variables on the participants. Rather, it lets the meaning emerge from the participants. Concepts, data collection tools, and data collection methods can be adjusted as the research progresses.'

Bryman (2001), Gibbs (2007), Silverman (2015) and the Web Centre for Social Method Research (2017), identify four main qualitative method approaches. Methods include ethnography (anthropology and culture); field research/physical observation with testing; phenomenology (human perceptions/psychology) and grounded theory. Qualitative method characteristics depend on non-calculable data and information based on subjective, stakeholder perceptions. They develop from an established question/s or set of research hypotheses. Methods can consist of theoretical rather than empirical data with pre-defined variables. Methods derive from certain questions and subsequent grounding/observations. These include recording researcher and stakeholder insights to provide insight into a problem. It can include interactive or interpretive methods to connect theory with data. These often involve a literature review or stakeholder consultation through common method, data collection instruments of surveys, workshops or semi-structured/structured interviews. Method characteristics are summarised in Table 3.1.

Table 3.1: Qualitative Method Characteristics

Theory	Data Collection	Characteristics	Evaluation Criteria
Ethnography	Secondary data analysis Field work, Observation, Surveys/Interviews, recordings, Anthropology	Individual factors not overall theory. Purpose sampling Narratives Extended contact	• Coding • Consistency • Credibility • Reiterative process • Reliability • Repeatability • Sample Size • Transferability • Validity - Internal/External • Ethics
Field Research	Case studies, testing, experiments, surveys, interviews	Analytical Framework	
Grounded Theory	Surveys, interviews, various data	Multiple sources influence literature/data/theory Pre-testing. Results develop theory Theoretical sampling Conceptual Framework	
Phenomenology	Case Studies Theoretical Models	Theory develops results Data is selected from single source Theoretical Framework	

Source Author.

In reviewing method approaches from the above search criteria and KRQs, qualitative methods are the most established. Ethnography is overwhelmingly ignored in favour of the other three methods. Existing field method examples include linking regional, climate change risk qualitative analysis with stakeholders in public forums. This presents an inclusive, interactive approach to obtain data and develop theories. Examples include IPCC (2010) and McNaught *et al.* (2011) for Pileni Island, Vanuatu. Dumaru *et al.* (2011) offers a grounded theory example (Table 3.1) for three Fiji villages: Bavu, Druadrua and Navukailagi. This method is simple, repeatable and transferable, following selective coding. 85/122 provided a reasonable sample size, given the population. A 69.7% response rate offered greater validity. It increases validity, reliability and consistency with multiple case studies and follow-up surveys for the re-iterative process. This approach is also particularly favoured for the Pacific region, specific nations or technical case studies. Examples of research via collaboration include Anderson and Wongbusarakum (2009) and Emaurois (2012). These involved stakeholder workshops for Micronesian communities. Stakeholders complement literature through a specific, local, context. They avoid repeating previous research limits. Field research is necessary to compensate for insufficient data available. This is essential where previous studies have not provided specific information/insight for MSCs.

No methods have been previously applied to Pacific MSCs and climate change, risk management in past studies. This thesis proposes a mixed method, including key qualitative method characteristics, approaches, advantages and stakeholder recruitment for data collection. Including this grounded method and direct data collection approach presents certain advantages. Qualitative method advantages include providing background and insight into factors affecting risks, challenges, costs and constraints for MSCs and stakeholders, as well as directly accessing information. This is otherwise difficult to obtain for many remote, small, developing, nations with limited institutional capacity. This thesis applies this method through Pacific case studies (Chapters 5-7). It incorporates interaction with informed stakeholders.

Existing approaches generally involve phenomenology methods with risks and impact cost, perceptions. Far fewer grounded method examples exist. General climate change, risk management and impact studies focus on ecosystems, populations, communities, agriculture and aggregate, economic sectors. These frequently ignore methods for specific stages, stakeholders and products/commodities. They have mainly concentrated on ports, shipping, intermodal transport and supply chains as separate stages. None exists for assessing climate change impacts on general or Pacific, MSC's. Becker *et al.* (2011) was among the first to use a qualitative research, perception-based survey to identify climate change risks, impacts and adaptation solutions for ports. They consulted 208 IAPH stakeholders with 93 responses. 53% considered climate change would affect them. 88% agreed more research was necessary to understand its impacts. From Table 3.1 criteria, the sample of 1,056 ports from 195 countries ensured the method was valid. Results were consistent across regions, countries and question types. The method is transferable to other case studies; being transparent and repeatable in clearly specifying questions.

However, with such a large sample size, inspiring follow-up studies for a re-iterative process may be constrained. The source ignored a re-iterative process to consider if results changed over time. It did not specify details over coding of follow-up interviews. Kretsch (2016) evaluated adaptation leadership in a Providence case study. Using Table 3.1 criteria, this phenomenology example consulted a small sample of 30. 25 responses and only 7 interviews limit the results' validity, transferability and reliability. Stakeholders considered pre-set data and theory relating to resilience strategies rather than influencing theory, as for grounded methods. No indication was given over coding. A once-off workshop avoided the re-iterative process's value. This survey method provided advantages of analysing stakeholder perceptions towards climate change; the extent of their awareness and prioritisation of adaptation solutions. Advantages are incorporated into this thesis's integrated research design. UNCTAD (2011) similarly used a survey instrument among its 200 members to identify port vulnerability to climate change risks and associated adaptation responses. However, existing sources primarily concentrates on port administrators ignoring entire supply chains. Being qualitative/phenomenology based, these sources do not provide specific, ground method advantages.

The following studies affirm existing, phenomenology method approaches with similar data collection instruments outlined in Table 3.1. These apply conventional risk management theory, rather than grounded theory. However, they fail to provide any empirical means to quantify risk probabilities, perceptions or impact costs. McEvoy and Mullet (2013) utilise workshops as an alternative qualitative method designed to ascertain Australian, port stakeholder perceptions and actions over adapting to risks and impacts. It uses case studies for Gladstone, Sydney and Port Kembla, seeking to pre-validate its proposed risk-vulnerability method. Its sample size of 41 appears reasonable to validate the model but low given the number of workshops. It provided four stakeholder consultation workshops to test the model and three follow-up workshops to incorporate feedback, adhering to the re-iterative process. The model appears theoretically valid, based on favourable stakeholder perceptions but inaccessible for separate external validity and reliability. The source provides insufficient information to determine if results are repeatable, consistent or transferable to other ports, stakeholders, risk types and scenarios. In not providing individual port specific issues and insight, the method ignored its theoretical value, which would have improved its application and value. It ignores extending a vulnerability-risk assessment and stakeholder consultation, approach across the entire supply chain system. In contrast, industry assessments of adapting supply chains to climate change include CSR (2011) and BSR (2015). These ignore theory in favour of specific case studies based on qualitative descriptions of risks, impact costs and adaptation solutions via surveys and interviews.

A number of climate change survey studies including UNCTAD (2011), and Kreie (2013 for global supply chains) also selectively ignore key supply chain stakeholders as economically peripheral. This chapter agrees with Becker and Caldwell (2015 for a Gulfport and Providence, USA, seaport case study). It argues impact and adaptation strategies can no longer be limited to consulting direct stakeholders involved. Ports alone are insufficient and uninformed to resolve potential event disruptions on MSCs. The studies' method weaknesses consider stakeholders involve too much time, resources and effort to incorporate a risk event's economic impact in methods. Kreie provides a phenomenology approach using a case study and interviews based on Table 3.1 criteria. Its sample size includes 17 stakeholders across a coffee supply chain. This increases validity as comparable studies frequently interview only 5-15. Its external and construct validity is extended through being pre-tested for tea, (with similar risks). These test a pre-conceived theory model for inter-organisational learning, using inductive criteria to validate its theory from aggregated results. Reliability and transparency are increased through a database of results and clearly published questions. The interpretivist perspective considers the method provides greater individual insight and background context into understanding specific issues. Relying on interviews however, reduces model consistency and validity within a re-iterative process, as results are more likely to vary and less likely to be transferable to other applications. However, they can further validate an overall theory, especially for exploratory research such as climate change and MSCs.

Qualitative method approaches have several research advantages (Bryman 2001; Gibbs 2007; Silverman 2015) including recording human interaction, insights and risk perceptions. They permit a diversity of perspectives and greater insight into specific factors/issues beyond pre-defined variables and methods. They allow greater flexibility in developing theories, methods and approaches rather than pre-created hypotheses. It overcomes common research issues of limited relevant data and directly access qualified stakeholders' experience/knowledge. Grounded theory advantages include linking theory to field research to validate results and observations, obtaining specific insight into key research objectives. This is increasingly favoured by Pacific field research reports e.g. SPC (2015b), with its recent Pacific Resilience Program. This thesis identifies the need to consult key stakeholders for grounded theory to obtain accurate risk, impact costs and adaptation solution information. Few relevant data methods involving empirical, case studies exist. This grounded theory approach therefore improves research credibility and accuracy when accessing primary information for an integrated, mixed method.

Qualitative research advantages are primarily limited by researcher capacities. This produces potential researcher bias, especially for grounded theory approaches. This contrasts with quantitative methods that are replicable and scientifically independent (Bryman 2001; Gibbs 2007; Silverman 2015). A qualitative interview/survey approach commonly assumes stakeholders are accessible and informed. Fussel (2007), Granderson (2014) and National, Cooperative, Freight Research Programme (2014) presume this for climate change impacts on transport. Existing survey methods primarily concentrate on developed countries. These assume stakeholders possess significant financial, skills, time, data and other resources to provide enough information. Thornes (2012) affirms this for a risk analysis of the UK transport sector. Sample size included over 700 people in 28 workshops and several stages of re-iterative testing, to ensure model validity, transferability, reliability and consistency. This indicated coding challenges over diverse data, adhering to Table 3.1 criteria. However, the time, resources required and complexities involved in establishing direct stakeholder participation, provide significant constraints to field research and grounded theory approaches. This particularly applies to small, Pacific archipelagos. Researchers reject field method, case studies as requiring significant time, finance, access, communication and other resources from stakeholders. Given the Pacific region's geographic isolation/large distances, very few theorists actually test their proposed methods and solutions. Examples of this major method, flaw include Kitty (2013); Ng *et al.* (2015; who propose a fuzzy risk approach for climate change effects on ports).

Phenomenology method disadvantages include challenges ensuring external reliability and validity. This influences a response bias, which assumes stakeholder familiarity with climate change, estimating risks and impacts, not scientific evidence or empirical data. Methods may be biased from stakeholder perceptions; leading to risk underestimation or overestimation. For example, McNamara, Hemstock and Holland (2013) used interviews and a community survey on the effectiveness of adaptation strategies. A psychological bias affects certain survey answers. It offers a field research example of method characteristics identified in Table 3.1 for Pacific risk, adaptation strategies. It's survey response rate was 50% with a sample size of 31. This increases greater model validity and reliability, given diverse stakeholders, risks and projects. Interviews and surveys adhered to selective coding to ensure question categories. Data results remain consistent when new data and responses are recorded.

The above method is likely to be repeatable and transferable to other examples with clearly defined stages, questions and coding. The process avoids theoretical sampling issues, where results analysis influences subsequent data. The method experiences issues of external validity and consistency based on bias. Aid agencies and communities may seek greater funding and publicity through myriad workshops rather than focusing on implemented, adaptation solutions. They may be ignorant or exaggerate costs, consequences and solutions (Trundle 2015 for Port Vila Vanuatu). Qualitative research method characteristics also ignore results that are more inconsistent over quantitative approaches. Some consulted stakeholders may face asymmetrical information relating to climate change. This complicates calculating risks, costs, benefits and consequences (Mach 2008; IPCC 2013; US Accountability Office 2015).

3.2.2: Quantitative Methods: Simulation and Mathematical Modelling Methods

This section reviews quantitative, research methods applicable to climate change impacts on MSCs. It divides these into two groups: simulation/mathematical modelling along with probability, econometric and other quantitative methods. These consider separate theories, characteristics and diverse applications for MSCs. However, they both involve a relationship between two or more pre-determined variables. Methods aim to be objective, reliable, valid and replicable. They incorporate data collection methods, advantages and disadvantages. Quantitative method characteristics quantify answers to an initial question/hypothesis. They consist of data from calculations, probabilities or modelling. Methods differ, relying on underlying, empirical assumptions and a logical framework, rather than stakeholder perceptions. Quantitative approaches lack a reliable research definition and description to assist stakeholders. However, references generally agree on the following characteristics (Gibbs 2007; Silverman 2015). From Bryman (2001, pg. 17), quantitative research is defined as:

> 'Methods entailing the collection of numerical data and exhibiting a relationship between theory and research as deductive, a predilection for natural science approach, and having an objectivist conception of social reality. The most popular research methods include closed-ended questionnaires, experiments, correlation, content and regression analysis methods.'

Other sources for climate change and risk management research depend on the IPCC reports. The IPCC defines simulation and mathematical modelling methods as:

> 'Models representing physical/mathematical processes in the atmosphere, ocean, cryosphere and land surface. These model various climate change risks to imitate the impact throughout an ecosystem or mainstream activity, economy, system or sector over time in response to specific risk events,' (IPCC 2015 pg. 47)

Simulation method approaches can be applied to climate/climate change and risk management models. They are based on stakeholder perceptions/surveys and mathematical models with interactions of variables. For example, Markovian chains are used to model supply chain disruptions. Simulation method characteristics applied to climate change, typically combine climate related inputs e.g. sea level rise (SLR), temperature, precipitation, wind, storm and cyclone intensity. When analysed, methods provide risk identification as risk event processes. Impact drivers form related consequences for specific variables and sectors. Models advocate risk solution responses. Specific simulation methods include Applied Dynamic Analysis of the Global, Regional and Country Specific Economy (EPA 2008); and Intertemporal, General Equilibrium

Model (Maunsell 2008). SIMCLIM provides a spatial and temporal, assessment model that integrates climate and environment. It is capable of analysing climate change and variability for New Zealand's economy (New Zealand Ministry for the Environment 2005). This source's method specifically models IPCC scenarios with climate input variables. Variables include precipitation, saltwater intrusion, SLR and short-term oscillations, erosion, storm surges and extreme tides. The datasets compare 1970-1999 to projections in 2070-2099. As with most equivalent studies, its performance is not connected to unique indicators. Inputs or independent variables are downscaled to assess risk consequences on transport, electricity, health and urban environment as dependent variables. However, models indicate localised risk trends and cost projections from aggregate, global models.

Asian Development Bank (2013) proposes a similar model for climate change impacts on a general economy. It includes standardised future scenarios of IPCC projected risks for 20 general circulation model examples. These models downscale 20 km^2 risks to a localised Pacific level. Although each model differs, core independent variables include those relating to atmosphere, ocean, sea ice, coupling and land. Datasets range from 20-175 years for climate risks including humidity, SLR, temperature, wind, precipitation and air pressure. Model performance is proven by the extent to which existing data is verified by simulations and experiments. For example, Canada's CCCMA-CGCM3_1-T63 Model predicts Polar Regions will achieve equilibrium in 80 years, before rapidly declining. Model characteristic variations link risks with aggregate, economic impacts as output (or dependent variables). These impacts are applied to mathematical modelling methods i.e. computable general equilibrium.

Simulation methods deviate in not using physical data collection. Models differ in variables, scale, complexity, spatial resolution, time period, length and form. These include either using a bottom-up or a top-down approach. A top-down, method applies a general/global, climate model and input risk variables to be downscaled to a regional/local scale for specific outputs or indicator variables. This aims to define local resilience, vulnerabilities, impacts and risks from climate/non-climate drivers. It estimates event impact across a national, regional or global scale including economic sectors. Koshy (2008) applies a similar SIMCLIM, simulation model directly to the Pacific. This models climate change effects on the islands of Viti Levu (Fiji) and Aitutaki (Cook Islands). It recommends including the baseline climate within an integrated, assessment model and sensitivity analysis, prior to testing various scenarios and related, biophysical impacts. Model climate variables included SLR, rainfall, cyclones, significant wave height, wind and drought. Koshy provides a simulation model advantage in adjusting for variable uncertainty, when utilising actual time series data. The model's performance was substantially improved with greater variable inclusion. Both produced an R^2 of 0.8945 when downscaled, compared to 0.4389 for a GCM model. It also includes a simulation advantage including non-climate factors accelerating climate change's impact, e.g. poor governance and ecological resource usage. However, it excludes risk assessment scenarios on a particular economic sector, to determine the impact of a specific, risk for a particular commodity.

In contrast, risk simulation method models can be defined as:

> 'Those used to model/replicate the probability of different outcomes, in a process not easily predicted via probability distributions, due to the intervention of random variables,' (Investopedia 2017).

Standard risk management methods include cause and frequency analysis, Bayesian networks, HAZOP and What If? They include Monte Carlo simulations, VAR, real options approach, transactional costs, resource dependence theory and risk event/fault trees (Ellis, Shockley and Henry 2011; Kern *et al.* 2012, Ghadge and Kalawsky 2015). These methods approximate experiments or field research. Approaches model outcomes in response to specific inputs, conditions and risks. Method advantages and characteristics offer permutations to adjust for uncertainty, where results cannot be replicated in objective reality. Chapters 2/3.3 emphasise how these risk management methods fail to consider climate change and MSCs. Risk model characteristics include assessing potential risk consequences upon a specific country, economic sector, ecosystem or other adversely affected, supply chain stage. This thesis classifies related sources with standard risk-management theory characteristics as simulation methods. These mostly possess no specific probabilities, impact costs and field research conducted. However, they are frequently misinterpreted as pure quantitative methods.

Simulation methods are based on pre-determined hypothetical assumptions, parameters, variables and conditions that can be swiftly altered. This contrasts with qualitative/quantitative approaches reliant on physical data. Simulations minimise human interaction except from pre-defined inputs. These ignore probability distributions/data. These methods aim to ascertain the qualitative likelihood of risk events occurring, adding stakeholder risk perceptions into climate models. Examples including Hawkes *et al.* (2010), Mitsakis *et al.* (2013) and Paeniu *et al.* (2015) concentrate on assessing logistics risks and vulnerabilities. These are based on stakeholder's perceptions over the probability of a risk occurring and its consequences. Ng *et al.* (2017) target current vulnerabilities and future risks for several port case studies including Canada, Australia, New York and Japan. This offers an alternative risk evaluation method combining risk management and vulnerability. However, it focuses on socio-economic variables affecting risk. These include demographic growth, technology, economic and institutional policy change as scenario inputs, rather than specific climate change risks. It indicates climate change risk perceptions not actual risk measurement. It details how alterations in risks can generally disrupt port operations. However, it completely ignores an MSC or supply chain context as specific examples. These sources provide no case studies that calculate risk probabilities and impact costs with specific values. Utilising empirical data, neglected by the study establishes whether risks present a continuously increasing threat. Providing multiple risk management methods recommending stakeholder risk identification; creates unreliable risk expectations, given demographics/experience. Ng *et al.* (2017) also fail to evaluate how effective these existing risk management methods are. They present no post risk-adaptation or measurement studies assessing impacts on performance/other criteria.

Scott *et al.* (2013) target current vulnerabilities and future risks for Australian ports, as an alternative risk evaluation method combining risk management and vulnerability. Its methods focus on socio-economic factors affecting risk. Variables include demographic growth, technology, economic and institutional policy change as scenario outputs, rather than specific risks. It's method characteristics detail how alterations in risks (as independent variables can normally disrupt port operations. It simulates intense rainfall, winds, storm surge, fogs and heatwaves as inputs. Port futures were assessed for the 'most likely future (MRI 2.3.2), hot/dry (CSIRO3.5), cool/wet (MIRocc/MidRes) and wetter futures (HighRes models). It considers a port's functional capacity. This method proposes standardised risk management theory flaws relying on subjective, risk perceptions rather than objective data. It provides no empirical case studies to validate findings.

Lam and Su (2015) also model disruption through risk as variables against projected consequences. They detail various adaptation strategies for Asian ports. It's database covered 2000-June 2011 (7 India, 3 China, 1 Taiwan, 2 Japan, 1 Bangladesh and 1 South Korea). Risks were calculated as average number of disruptive occurrences per year for 15 disruption risk variables. Severity was quantified as total throughput (tonnes) divided by 365 days, multiplied by the number of disruption days. It's model performance produced a simulated 2x2 risk assessment sequence but only for low probability, high impact events and high probability, low impact events. This method's underperformance is indicative of a general trend of how standard risk management fails to protect MSCs from climate change. It specifically prioritises other risks, without risk evaluation or prioritisation criteria. These sources are flawed in multiple aspects in underestimating risk. They focus only on port specific areas rather than an entire supply chain. No method connects to climate change projections and it ignores multiple stakeholder relationships.

Numerous mathematical simulation models exist outside conventional risk management and probability theory. However, very few examples including Markovian chains specifically apply to disruption risks. Methods equally ignore this thesis's focus of climate change impacts on Pacific MSCs, any supply chain, stage, commodity or stakeholder. As one of the main risk analysis and evaluation methods, Markov chains are used to analyse a system's dynamics. This involves the transition from one step to the next with uncertainty. They are defined as a stochastic sequence of random variables with a transition, probability sequence, static through time, present in discrete space. (Gujarati 2011). As with simulation methods, characteristics include establishing variables under conditions of uncertainty to produce outcomes. Markov properties include the future depends on present values but is independent of past values. They can be adjusted to involve stakeholder/other inputs with a propagation sequence. This models disruption risks in response to given, risk scenarios. An example is Gurning's application of Markov chains (2011) for an Indonesian-Australian wheat supply chain. This modelled 16 potential, maritime disruption variables as a transition state. It modelled related causes including severe weather, security, port congestion, earthquakes, political events, port related equipment and customs clearance. However, it ignored climate change. Gurning also applied expected frequencies and risk probabilities to minimise uncertainties and anticipate actual event consequences. The model used six variable categories including performance indicators, transport objectives, risk state definition, probabilities scenario, disruption management strategies and expected future probabilities and consequences. This method failed to replicate and test risk conditions in objective reality.

All three simulation approaches and cited sources possess a number of commonly identified, research method advantages and disadvantages (Bryman 2001; IPCC 2015; Silverman 2015). Simulation advantages include providing insight where actual data is limited and conditions are uncertain. They are cheaper, quicker and require fewer risks/resources than physical experiments. Simulation testing is also more flexible to adjust, prior to undertaking experiments/interviews. This increases accuracy, efficiency, simplicity, reliability, consistency and precision for researchers and stakeholders. It enables complex issues to be conceptualised, for results too complicated or challenging to replicate in reality. Simulation approaches enable the testing of hypotheses and concepts to enhance understanding/provide insight and feedback. They aid more effective decision-making. This includes risk management theory. Given climate change impacts and risks entail multiple dimensions and factors, simulations reduce potential maladaptation risks.

Tetra-Tech (2014) summarises various applications of Caribbean, risk assessment models and methodologies. This is a similarly affected region of small island, developing states highly vulnerable to climate change risks. Method stages assess risk, combining long-term and short-term, sudden direct impacts, first on assets and operations and then on the surrounding area of influence. Its climate variables use temperature, SLR, precipitation, hurricane frequency and intensity and storm surge for a Caribbean dataset. Dependent variables are linked to vulnerability, exposure and adaptive capacity. It's risk-hazard assessment evaluates qualitative responses to simulations and hydrological, hydraulic, erosion, wave and run up models. It's model performance is conditional upon the extent to simulations are accurately forecast i.e. for the Dominican Republic various models indicate precipitation will decrease and temperature increase by 2050.

Messner *et al.* (2013) and Chhetri *et al* (2013) provide a simulation method assessment of climate change impacts on ports to identify asset exposure to risk. Chhetri *et al.* (2013) extends simulated risk analysis to integrate three-dimensional impacts and vulnerability through physical asset and land risk modelling (LIDAR) in a GIS Asset Register. Thirty climate risk variables are considered. It simulates risks utilising a CTOS. Three case studies – Sydney, Port Kembla and Gladstone - are provided. The model performance is ascertained through indicators of port environs, infrastructure, geography and users' willingness to participate. Key performance indicators include crane rates, yard utilisation, truck queue length and other port operational parameters. E.g. a 2030 heatwave scenario created a minimum loss of 241 containers per year compared to 183 at present. However, the method does not evaluate these numerically, preferring qualitative risk assessments. Given advantages in identifying specific risks for individual stakeholders and overall supply chains; this thesis integrates simulation methods. It applies these method characteristics through local risk projections. It analyses implications for MSCs via a systematic, vulnerability-risk assessment.

Simulation method disadvantages include scarce, relevant model applications and the complexity of isolating a single commodity's total event impact, (even if economically significant). Methods do not provide various risks' specific, impact costs, needing econometric methods. (Gujarati and Porter 2011; IPCC 2015; Silverman 2015). This flaw is particularly significant, given developing country constraints in accurately forecasting impacts. This was noted by McCubbin, Smit and Pearce (2015), for multiple event drivers in Funafuti, Tuvalu. Few estimates exist, compared to studies proposing their risk assessment and simulation method approaches. One major method disadvantage is that simulations are based on theory hypotheses for specific scenarios, variable assumptions and boundary conditions, not reality. These frequently ignore key stakeholder experience. These sources fail to test the consistency of past and future, risk event and impact cost projections with actual, observed data.

Simulation methods disadvantages include failing to provide standardised definitions, assessment criteria and methodologies for climate change risks, probabilities and impacts on supply chains. Simulation approaches typically rely on qualitative perceptions for risk assessment (ADB 2013; Cox 2013; Monnereau and Abraham 2013). In contrast this thesis considers numerical approaches for impact costs and risks, using time series data and probability distributions. This minimises reliance on differing perceptions of what risk, severity, vulnerability; resilience, impact, adaptation, likelihood and consequence mean for each stakeholder. This improves standard, risk assessment models. It assists and increases physical, psychological and institutional stakeholder adaptive capacity. It minimises bias when considering an affected global supply chain systematically. Other risk simulation method flaws include complexities in forming probabilities from subjective understanding of risks. They are constrained in requiring significant time, money and other resources, complicated further when these non-field studies provide unclear indications of how risk probabilities can be calculated for stakeholders. Most conventional risk prediction models (including existing event trees), are static (Ellis, Shockley and Henry 2011; Kern *et al.* 2012, Ghadge and Kalawsky 2015). These assume time remains constant or base probability solely on time series data. However, these ignore/marginalise the projected rate or increase in the probability of an event occurrence, its duration, frequency and intensity. Risks can be swiftly multiplied thorough vulnerability, resilience, adaptive capacity, and increased interdependence.

Other simulation method disadvantages include asymmetrical information, unreliable and inconsistent scenario analysis and data. These methods based on unjustified, initial model assumptions, hypotheses or parameters frequently incur problems of oversimplification, informational and situational bias. Many survey studies include commissioned government, industry or NGO reports, not impartial, peer-reviewed literature. Examples include Garnaut (2012) for climate change effects on Australian infrastructure, PCARFI (2013a) and SPC (2014). Sources proposing simulation model methods include World Bank (2010), Bojinski (2014), Cooper and Pile (2014). Their method weaknesses assume these nations can calculate risk probabilities and accurate, accessible, related information exists that is updated and consistent. Given global and

Pacific regional climate change projections remain uncertain, identifying risks and probabilities can produce inconsistent and unreliable results. This creates uncertain methods when assessing associated impact costs. These particularly challenge Pacific countries with limited institutional capacity for data collection and mathematical/simulation modelling, analysis.

3.2.3 Econometric, Probability and Non-Mathematical Model Methods:

This section evaluates other quantitative approaches including probability and econometric regression methods. This assesses climate change risks and impacts for MSCs. Unlike qualitative data, these approaches' research designs, methods, variables and hypotheses are pre-determined. Risk management method characteristics identified in existing studies aim to estimate risks on various activities, stakeholders, assets or infrastructure. Current examples seldom apply this for entire supply chain systems, (Rehdanz 2004; Simpson *et al.* 2010; Australian Department of Climate Change and Energy Efficiency 2012). Very few satisfying these characteristics, with actual values and equations provided; have been located, (even for individual supply chain stages). Existing related research favours standard assessment methods, results and solutions from qualitative data (Das 2006, Coleman 2006). It frequently omits equations, actual probabilities, risk model characteristics and assumptions. These sources propose risk identification but do not prove methods from theory or through probability distributions (Conrow 2003, Ong 2006). However, effective risk management applied to climate change and supply chains requires understanding of probability distribution characteristics. This validates this quantitative approach rather than only employing phenomenology methods of risk perceptions using surveys/interviews. This is proposed by few risk management sources (Sutton 1992; Koller 2005; Garlick 2007).

To justify the proposed section 3.3 framework for risk identification; it proposes any equations and theory are confirmed through Poisson distribution characteristics. These are vindicated in standard econometric textbooks (Manfield 1991; Gujarati and Porter 2011). It satisfies the following assumptions. First, it must be possible to divide the time interval used into large areas with correspondingly small probabilities of an event occurrence. The probability of a risk occurrence in each sub-interval must remain constant through the period. The occurrences must be independent across any sub-interval i.e. the two variables do not affect each other. Expected frequency values are computed separately for each level of one categorical variable at each level of other variables. Poisson probability distribution can be tested and applied to estimate the probability of a climate change event using historical information: This derives Equation 3.1 to calculate the historic probability of a risk event occurring.

$$P(x) = \frac{e^{-\lambda}\lambda^{x}}{x!} \; for\ \mathrm{x} = 0, 1, 2 \text{ and } \lambda > 0 \quad . \qquad \textbf{(3.1)}$$

where: **x** = number of climate change, risk events
p(x) = the probability of x risk events occurring in the given time period
λ = the expected (or mean) rate of occurrence of the climate change, risk event in the designated time period
e = Euler's constant, $\approx$ 2.71828

The Poisson mean equals its variance $\mu = \lambda = \sigma^2$. The Poisson distribution is useful in modelling risk events such as climate change based on the following theoretical assumptions. It calculates the probability of x occurrences per unit time, allowing for fewer observation values than the normal distribution with a normality assumption for a continuous distribution of all possible values. Its advantage occurs in being able to determine how many risk events were observed/did occur but not to determine the number of events that did not occur. The distribution only requires the mean number of occurrences and range. The validity of the Poisson distribution over others can be reaffirmed through the Chi square test. This uses the null hypothesis **H_0:** The distribution follows the Poisson distribution. As provided in standard textbooks on statistical probability theory (Levin and Rubin 1991; Gujarati and Porter 2011); this test is used when two variables exist from a single population/data sample. This tests for variable independence or if a significant association exists between the two variables, based on the above hypotheses (Lind, Marchal and Wathon 2012). This indicates whether an observed frequency distribution approximates the Poisson distribution with several degrees of freedom. The longer the data interval, the larger the probability with discrete rather than continuous, random variable values.

The Poisson distribution can also link to determining the conditional probability of a MSC asset failure from a specific climate change, risk event for KRQA unlike other distributions. A Poisson distribution's advantage includes approximating the binomial distribution if the number of trials is very large and the probability of occurrence is very small. The binomial distribution does not apply to time series data where n independent Bernoulli trials exist. Binomial distribution assumptions are the number of trials, is fixed and only two outcomes, "success" and "failure" exist. Climate change isn't risk static with a fixed number of independent trials. Its risks are more frequent in recent years across all locations and risk types. Risk events are not mutually exclusive for climate change. The thesis equations consider events to be based on accumulated risk, future risk or the joint probability of two risk events occurring simultaneously.

The normal distribution is not favoured for various reasons. These are based on certain issues identified by Taleb (2001) in the Black Swan and this section for low probability, high impact cost events. The probability of the sample population mean is not always close to the normal distribution. Given low lambda ranges for time series data and expected number of observations, the Poisson distribution is more mathematically valid since the normal distribution is recommended for large sample values – i.e. when λ>1000. The normal distribution focuses on mediocrity, average or expected values, considering sudden risk events within the Gaussian bell curve unlike the Poisson. The Poisson can incorporate average/expected value, joint probability, and accumulated risk value increases. Although the Mandelbrotian is preferable for fractal randomness of events (where the ratio is preserved across scales) (Taleb 2001). Unlike the Gaussian; it ignores time series data with average/expected values). Deviations may potentially exist across any time series, data period, risk type and location. This cannot be sufficiently accounted by the Gaussian curve. Yet the Poisson provides a greater approximation of risk than the normality distribution. The Gaussian bell curve is un-scalable, underestimating tail end, risk events, especially for impact/probability of occurrence. Its theory limitations assume risk decreases exponentially, not increasing with observations/over time and values away from expected values. The normal distribution ignores significant increases in trends as potential results.

Climate change risks assume outliers in time will become more frequent. The time series data and derived equations do not reflect normal distributed, data assumptions but reality, which in addition incorporates scalable randomness. Based on certainty and these data assumptions, random selections do not apply to climate change events with multiple variable parameters of uncertainty, about the frequency of specific risk event types in a given year. Standard deviation does not apply, as a number merely scalable to Gaussian bell curves. Significant deviations can occur in any particular time period, location and risk event type. Finally, even Monte Carlo methods based on theoretical risk simulations rely on Poisson distribution assumptions.

Quantitative, regression method approaches involve mathematical formulae, theories and assumptions to estimate climate change, impact costs and benefits. These are further analysed in section 3.5. Econometric/regression methods are also used in related risk management and impact cost studies e.g. Policy Research Corporation (2009). This evaluated an impact cost analysis for the EU coastal economy sector, including ports. Its dataset uses 15 nations. Simple regression and market valuation methods estimate costs for European assets within 500 metres of a coastline at $500,000,000-$1,000,000,000. Net adaptation benefits were estimated at 3.8-4.2

billion euros, depending on SLR. Its performance is undermined in providing only aggregate estimates and ignoring key impacts e.g. intangible costs.

Godwin (2011) suggests this method for Cartagena port, Columbia. The proposed thesis regression model adds a scenario, where estimated total costs and benefits are considered. Stenek *et al*. (2011) and Rycerz (2015) also apply a climate change, cost-benefit analysis to Cartagena port. These establish projections to examine specific consequences of event risk variables including temperature, precipitation, SLR and wind velocity increases for ports. Dependent variables indicate 13 major risk variable categories related to port performance. Variables include demand, trade level, trade patterns, navigation, berthing, goods handling and storage. Variables include social/environmental performance, inland transport, insurance, infrastructure, building and equipment damage. The sources' form a similar, financial based modelling approach. This calculates a port's economic impact costs with and without climate change. It then evaluates climate change impacts in terms of net present value (NPV) defined:

$$NPV = (B_0 - C_0)_+ \frac{B_1 - C_1}{(1+r)} + \frac{B_2 - C_2}{(1+r)^n)} + \cdots + \frac{B_n - C_n}{(1+r)^n)}. \tag{3.2}$$

This method's performance is ascertained by comparing costs and benefits for individual adaptation solutions i.e. for raising a causeway, with flooding costs of \$2,4,00,000 by 2030, (yet \$380,000 to elevate and adapt). It offers discounted and undiscounted estimates, to adjust for different time horizons and projected uncertainty. These add costs, discounted over future periods. It estimated business disruption costs compared to the extent of adaptation and insurance. As with existing quantitative approaches, these provide final values rather than exact equations. Possible risk costs and benefits are frequently summarised for ports and supply chains separately.

Kong *et al.* (2013) concentrates on refining an economic, impact analysis model for climate change for Australian port infrastructure. Its method is a life cycle costing model. This compares asset deterioration, inspection, maintenance, rehabilitation, salvage and other costs of not enhancing resilience for new and existing infrastructure. Independent climate variables include sea level, precipitation, temperature and waves. Dependent variables involve port, land, sea and transport assets including berthing structures, port protection barriers, superstructure, channels, basins, road and rail infrastructure. This is modelled in separate scenarios, using graphical user software and climate model variations. A seaport structure's lifecycle cost is summarised as

$$LCC = I_0 + C_I + C_m + C_R + C_s. \tag{3.3}$$

Where I_0 =Initial Cost, C_I = Inspection Cost, C_m = Maintenance Cost, C_R =Rehabilitation Cost, C_s = Salvage Cost

The method's performance considered multiple factors for risk probability and impact costs. For example, the probability of corrosion for a Gladstone port, concrete structure is estimated around 29% under a 2070 scenario. A risk and impact analysis concentrating on MSCs could incorporate a fixed constant. This considers an asset's actual value over its projected lifespan against its asset replacement cost, as an event consequence. This further helps to evaluate port infrastructure, structural resilience against projected disruption risks, answering whether adaptation costs are necessary and cost effective. This thesis methodology similarly considers ascertaining projected costs for long-term risks e.g. SLR and temperature, as a fixed constant. This can include factors occurring over an asset's lifespan e.g. repair, maintenance and replacement costs. It can also be adapted to different risk scenarios and time horizons along with measuring other assets not just port but other supply chain stages.

Sawyer (2014) also proposes an initial risk-vulnerability assessment to ascertain the extent to which specific disruption risks will affect projected impact costs for Canadian transport assets. A risk-vulnerability analysis also aids in determining specific risk locations and which assets to prioritise for stakeholders with scarce time, fiscal, skilled labour, technology and other resources. It links these to an economic impact cost analysis. Variables include direct, indirect and accelerated maintenance, asset costs. The model's performance is evaluated in output indicators for existing impacts. For example, a road from Tibbet to Contwoyto was open for 42 days. This contrasts with a historic average of 70 days. 13,000 tons of cargo and 11,000 of fuel was airlifted. An investment of $1,000,000 in Mississauga public infrastructure increased the GDP by $1,340,000.

Smith (2015) concentrates on applying the above economic, impact cost analysis for the ports of Bremerton, San Diego and Rotterdam. This can be adapted to Pacific MSCs stages. Including several case studies can further improve empirical model validity, impact analysis and underlying assumptions. This thesis proposes panel data for future research with several Pacific supply chains. Smith also affirms the necessity of stabilising a model sufficiently robust to consider climate change's dynamic nature and uncertainty through scenarios. It also proposes including cost-effectiveness analysis to measure the extent to which solutions justify adaptation costs. For example, for Bremerton-Kitsap it considers assets depreciate for only 32 years, yet projected lifespan is 67 years. Quantifying direct impacts as costs and benefits through the NPV standard equation above, can aid stakeholders to allocate scarce resources and prioritise adaptation strategies. Yet the method's performance is limited, as it does not calculate examples with specific probabilities of risk occurrence. Smith (2015) ignores risks or stakeholder concerns. The method possesses empirical concerns of cost estimation and optimization, without an integrated risk assessment mechanism incorporating direct and indirect, economic impacts with accurate risk projections. None of these studies considers results might vary between different ports, transport infrastructures or supply chains. However, this thesis methodology will include both. It specifically concentrates on how projected risk types, resources, constraints, adaptation policies, scenarios and impact costs may differ for Pacific MSCs.

Quantitative models have more flexible research advantages for climate change, impact methodologies (Bryman 2001, Gujarati 2011; Web Centre for Social Methods Research 2015). Utilising probability distributions identifies and provides risk estimates. It is cheaper, less time-consuming and safer than real risk events, especially with low actual probabilities of occurrence. Stakeholders can consider multiple outcomes, scenarios, possibilities, causes and responses based on hypotheses, parameters or existing information. This helps when limited data exists. This thesis's method improves upon existing qualitative method studies by including as many supply chain stakeholders as possible, for a single commodity. It incorporates customs, the financial and insurance sector, beneficiation, consumers, subsistence fisherfolk, ecosystems and small entrepreneurs. These stakeholders are all ignored by past cited sources.

The specific disadvantages of normal, Gaussian, binomial, Poisson and Mandelbrotian, probability distributions are previously summarised. Section 3.4 analyses advantages and disadvantages of climate change, risk probability theory applied to maritime and other supply chains. Sources failing to provide distributions for risk management are criticised for weak theoretical or quantitative methods. These often deny qualitative information aspects and practical solutions that might directly assist affected stakeholders. Current risk management studies ignore how probability distributions can include climate change. Examples include Australian Department of Climate Change (2010), Baker and Week (2013) and Cox (2013) for Pacific, climate change, consequences on coastal infrastructure. Mach (2012) notes advantages to including monetary valuation, co-benefits, risks, behaviour dimensions and uncertainties. He mentions profit-retention, commercial opportunities and self-interest. Business for Social Responsibility (BSR 2015) focus on economic and social co-benefits of endorsing increasingly sustainable, supply chain infrastructure and development. It points out ultimate survival. These provide more psychologically compelling arguments to reluctant stakeholders. This can convince them to prioritise and concentrate resources/efforts in climate change preparation, mitigation and adaptation. They offer further reasons to select adaptation including lower pollution, improved health, environment, economic activity, time saving, food and energy security. It further indicates potential cost consequences that not prioritising climate change immediately; or adapting globally will entail.

Quantitative models, information, effects and variables are often conditional on certain theoretical assumptions. Further research disadvantages include factors are often situation specific and lack specific relevance to this thesis's KRQA. This thesis agrees with Marra (2014) that many quantitative model-based approaches often ignore location/site, specific characteristics e.g. port, shipping, supply chain, commodity, event, environment and Pacific climate. Generalised methods frequently cause issues with related individual, stakeholder consequences, requirements, concerns and solutions. However, economic impact cost analyses for climate change provide certain advantages over qualitative research. These include more consistent, replicable, valid, objective and transparent data. This can assist to evaluate key research questions and consider relationships between variables. Impact cost analyses are however, rejected by Netherlands Environmental Assessment Agency (2014) for certain research disadvantages. Method applications seldom incorporate sudden, large scale, risk shocks and complexities in accurately calculating these costs. Often aggregate costs insufficiently allow for variance across individual stakeholder examples. Certain impacts are difficult to ascribe a pure economic value. These impacts include any environment, species extinction and life replacement costs or the opportunity costs of a commodity delayed through a supply chain (IPCC 2010).

3.2.4: Addressing Current Literature Method Gaps: Establishing an Integrated, Climate Change, Impact Methodology for Pacific MSC Stakeholders

Since Pernetta and Hughes (1989), no coordinated methodology has been identified and globally accepted for MSCs and climate change risks in other studies. Whilst qualitative, simulation and econometric/numerical methods possess certain characteristics, advantages and disadvantages summarised above, global and Pacific stakeholders lack a consistently defined method. Assessing these methods ensures the most appropriate, cost and risk-effective methodology is applied to this thesis. To address current literature method gaps, it proposes a synthesised, multistage methodology in subsequent sections. This chapter connects ground theory, simulation projection, probability and econometric methods to apply to MSCs. This is necessary given countless stakeholder constraints and the uncertainty of forecasting exact climate change impacts.

This thesis favours an integrated, conceptual framework providing accuracy, flexibility and other research advantages of a consistent and coordinated response. This seeks to combine research strengths with minimal, past adaptation method limits summarised in section 3.2. It retains the further advantage of adjusting for global, regional Pacific and individual, island specific variations in projected risks. It provides the benefit of field research visits for specific, Pacific case studies. It proposes all research stages chosen should satisfy several criteria to be included as an integrated methodology and conceptual framework, proposed to replace existing literature, theory gaps. Stages should be justified by significant peer-reviewed literature. Methods should be relevant and specifically apply to the thesis research questions. The researcher should identify each's unique, conceptual contribution over existing methods for Pacific MSCs. Methods should be logically consistent to support the thesis structure. To answer current literature and method gaps; this thesis establishes a combined climate change risk-vulnerability assessment, impact cost analysis and adaptation strategy, evaluation method. This includes stakeholder consultation to address KRQA-KRQC. Certain advantages exist in combining qualitative, simulation and quantitative methods in one conceptual framework. This addresses stakeholder concerns over uncertain, climate change projections, diverse methodologies and a lack of previous literature examples. This aids stakeholders, given geographical distances, time, financial and other constraints limit sample size, data and information availability of stakeholder consultation for Pacific and other developing states.

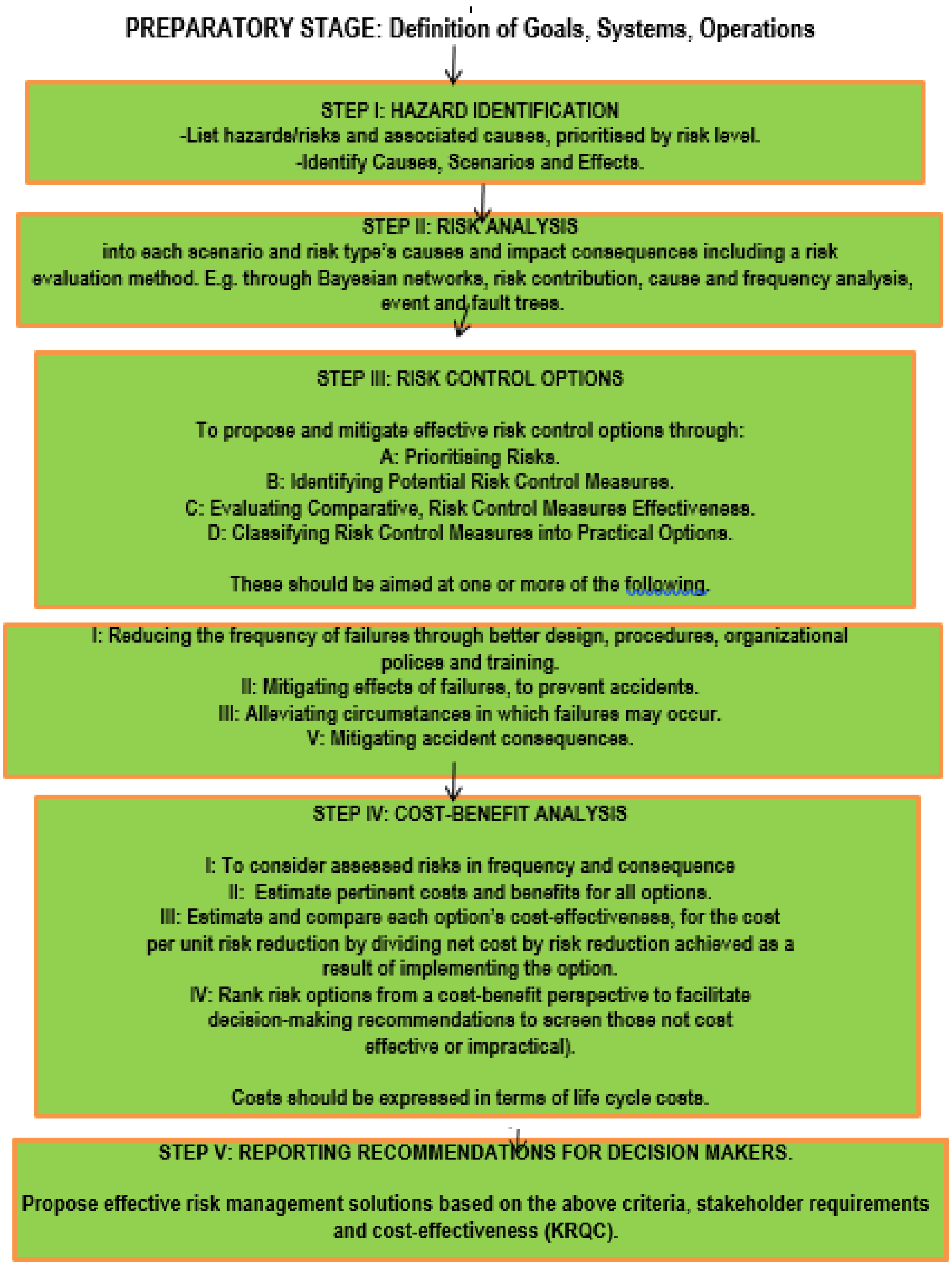
3.3: CLIMATE CHANGE RISK-VULNERABILITY, CONCEPTUAL FRAMEWORK FOR MSCs (STAGE II)

To address KRQA in Chapter 5, this method is proposed from risks identified through field research, stakeholder consultation and peer-reviewed sources. The IMO (2007), formal safety assessment model in Figure 3.1 advanced a framework for systematic risk identification, management and evaluation. This model incorporates a cost-benefit analysis for policy stakeholders (as seen below). This is conventionally utilised in formal, maritime safety conditions. Its advantages consist of incorporating both qualitative and quantitative risks with impact cost types from a stakeholder perspective. Kontovas and Psaraftis (2009) identify several model concerns; including determining which risks should be incorporated or which method to select. Methods to quantify risk and impact costs differ between decision makers. Limited historic data exists for certain risks and impact costs. It also cautions subjective risk control option and impact cost assessments based on stakeholder perceptions and differing factors affecting each specific risk.

This thesis's conceptual contribution represents the first interdisciplinary method application outside conventional maritime safety and risk factors for this framework. This further verifies its pragmatic approach for stakeholders. Unlike other methods, it is specifically adapted here to incorporate both climate change, impact cost analysis and adaptation strategies, to address KRQB and KRQC. As Figure 3.1 illustrates, this provides the advantage of being specifically applicable as a risk methodology framework, adapted to climate change risks for MSCs. It proposes first defining goals, systems and operations and applies this through KRQ's, defining climate change, MSCs and stakeholders/stakeholder requirements. The stages proposed are adapted and synthesised by this research method framework, through the risk-vulnerability sequence in section 3.4. This identifies, evaluates, prioritises and treats risks impact costs in stage III. These are adapted to different climate change scenarios, risk event types and time horizons along with locations, MSC stakeholders, stages and commodities. It provides this thesis's contribution to existing model/risk management failures. It proposes adjusting existing impact cost analysis, (section 3.5) to consider direct, indirect and intangible, (including nonmarket and ecological costs). It seeks to integrate these costs when assessing the comparative effectiveness of past, present and future adaptation solutions. It also considers lifecycle costs, (not just net present values when assessing long-term event impacts), in the theoretical framework below for impact cost analysis.

This method answers stakeholder concerns of diverse methodologies identified in literature. This complicates adaptation to increasing risk events predicted in Chapters 4/5. Its conceptual framework contribution to existing literature proposes this integrated risk sequence in stage II, after data collection in stage I, as a multistage methodology. Stage III incorporates an impact cost analysis and adaptation strategies for stage IV. Section 3.3.1 provides a combined conceptual method overview. This links climate change risks and impacts with MSCs. Section 3.3.2 identifies the proposed method's risk projections, scenario assumptions and time horizons. Section 3.3.3 identifies existing risk management method, issues and proposed, conceptual framework improvements. Section 3.3.4 combines these factors in a risk-vulnerability sequence to address KRQA. This aims to assess stakeholder awareness of risk consequences, considering the extent to which they can protect assets/modify resilience (section 3.5).

Figure 3.1: Formal Safety Assessment (FSA) Process



Source: IMO 2007, p.g 17.

3.3.1: Thesis Combined Conceptual Framework, Method Overview

To enable MSC stakeholders to prioritise a proactive risk-vulnerability, anticipation integrated method rather than reactive event approach; this thesis reduces potential asymmetrical information and uncertainty. Figure 3.2 summarises its combined method conceptual framework through a joint climate change risk and impact event tree. It summarises key MSC stages (orange), climate change risks (green), factors affecting the probability of a risk occurrence (blue), factors which influence supply chain vulnerability/resilience. These factors connect to risks (pink/red), direct (brown/orange) and indirect impact costs across the supply chain (green). Long term risks are highlighted in Figure 3.2. Sudden risks include climate change-related events. Other less investigated risks include solar radiation, increases in humidity, changes in pH salinity; cloud cover, evapotranspiration rate and fog. These are not specifically investigated from limited data but present a hypothetical, future research area.

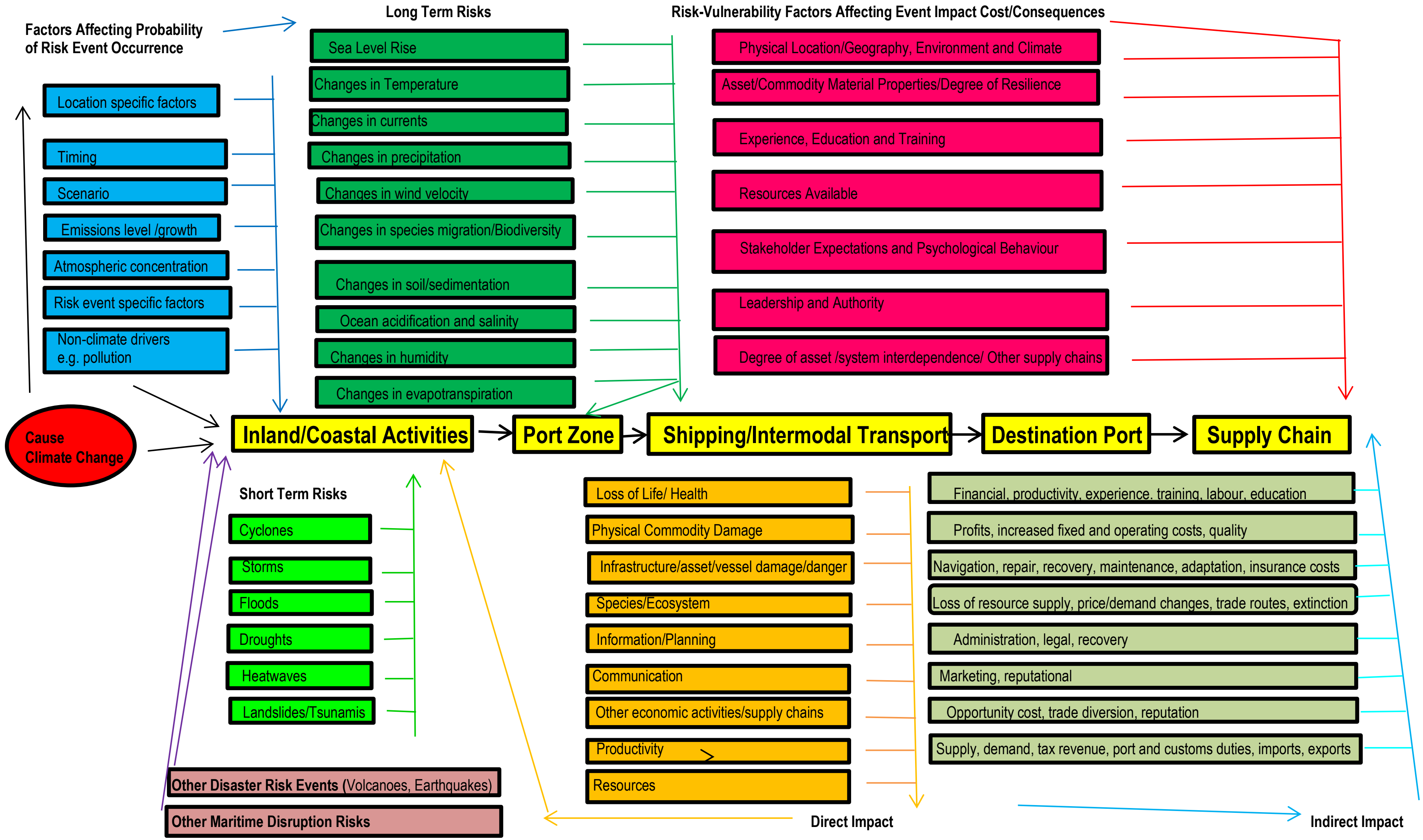
Climate change, risk event occurrence and vulnerability are conditional upon non-climate related drivers in Figure 3.2 e.g. population/economic growth, technological progress, production and consumption. These are held at constant growth rates autonomous of the climate change rate, scenario, time horizon, supply chain stage and stakeholder. This isolates direct risk attributable, impact costs for a Pacific MSC. However, this tree and conceptual framework's advantage includes flexibility to consider additional dimensions as information becomes increasingly available. This reduces uncertainty over projected climate change. This thesis also outlines factors which influence the extent of risk for a MSC commodity, supply chain, asset vulnerability and economic, impact cost sizes via Figure 3.2. These are ignored by formal safety assessment and other risk methods. Factors include projected design, material (labour, capital, technology, equipment and infrastructure), life expectancy, location and distance to event risks/pollution. Others include asset condition, past risk exposure, degree of climateproofing and the extent to which effective repairs and maintenance are conducted. Examples include Alesch *et al.* 2001; Handfield, Blackhurst and Elkins 2007; Moser and Ekstrom 2010). Existing coastal erosion, topography, demography and developments or land use may also affect a MSC's physical risk-vulnerability, to consider in forming an integrated methodology.

LEGEND

Factors Affecting Risk Causes	→	**Other Risk Types**	→
MSC' Operational Risks:	→	**Indirect Risk Event Impacts**	→
Long/Short Term Risks of Climate Change	→	**Factors Affecting Impact Costs**	→
Direct Risk Event Impacts	→	**Factors Affecting the Probability of Risk**	→

Source: Author.

Figure 3.2 Conceptual Framework for Integrating Climate Change Risks, Impact Costs and Maritime Supply Chains as an Event Tree



3.3.2: Climate Change Projections, Scenario Assumptions and Time Horizons

This thesis method specifically applies Figure 3.2's conceptual framework to investigate projected impacts for a short-term risk event, increasing year by year. It applies the framework for long-term risks to the three main IPCC (A2, A1B and B2) scenarios and time horizons. Scenarios are specifically outlined in Chapter 4 for Chapter 5's case study. This thesis-integrated methodology provides the research advantage of being specifically applicable to all IPCC projections, scenario assumptions and time horizons. This aims to avoid previous research limits. These identify projected uncertainty over climate change versus climate variability, future emission levels and the frequency, location, duration and intensity of risks.

3.3.3: Existing Risk Management Theory, Conceptual Framework Challenges

Existing risk management theory (section 3.2), provides significant flaws for climate change implications affecting MSCs. Risk management methods and theory assume risk probabilities are essentially static and one dimensional over a specific timeframe/scenario, without considering inter-dependencies or linking to other factors, which influence the probability of that risk occurring. It ignores accumulated risk, survival and resilience. It marginalises how risk can be measured in relation to performance, recovery time, cost and other indicators. To calculate future probabilities, the following risk factors (identified in pink in Figure 3.2) can be incorporated into conventional risk management: the type and nature of risk, physical and head office location, climate, environment, records, climate change rate, event timing, duration, intensity and frequency. Other factors combine degree of natural resilience, technical standards or service life and asset resilience or shock absorption capacity (Rowan *et al* 2013; Sawyer 2014; Schweikert, Chinowsky and Espinet 2014). Location factors that may potentially affect risk include shoreline proximity, coast/ocean and water sources, existing and planned structures and development. These include vegetation cover, soil, salinity, altitude, elevation and location of floodplains and natural coastal defences including seagrasses, mangroves and other ecosystems. Factors include the extent and condition of natural resources needed for a commodity in all production and processing stages, (Britton *et al.* 2011; Limalevu 2013; Metternicht *et al.* 2014).

Current research challenges include locating and establishing the information necessary to calculate risk probabilities for events and conditional probabilities for asset failures, given specific risks/events. Figure 3.2 considers risk event probabilities can be amplified through globalisations' just-in-time production, contract obligations, accumulated risk, stakeholder complacency, moral hazard and system interdependency. Factors which contribute to vulnerability, increase the probability of a risk event and conditional probability of a maritime asset failure. Redundant capacity in assets, systems and resources can minimise risk exposure. Factors enhancing resilience and adaptive capacity can minimise the conditional probability of failure and should be subtracted. This method approach provides guidelines for stakeholders to replicate and utilise.

This thesis method aims to overcome existing literature gaps across an entire MSC by proposing an asset, system, resource, ecosystem and stakeholder inventory. This prioritises the most significant supply chain risks in risk exposure and adaptation cost. It considers risk exposure to assess each asset's importance to maintaining supply chain performance, stakeholder requirements, operations and institutional capacity. Risks may also affect existing and future port assets' and systems' ability and capacity to be upgraded. Existing methods also have not considered how ports and other stakeholders' interdependencies of complicate identifying specific risks and impact costs for a single commodity or impact. Climate change events present impact costs to assets, ecosystems, operations, production, asset procurement, demand, supply, price, customer order fulfilment and reputation. Figure 3.2 highlights direct costs (orange) and indirect (light blue). Conventional risk management fails to prepare stakeholders to survive simultaneous, disruption risks. These methods ignore how to facilitate trade, supply chain performance; security and eco/commercial sustainability continuously (Brooks *et al* 2010; McEvoy *et al* 2013; Chhetri *et al.* 2015).

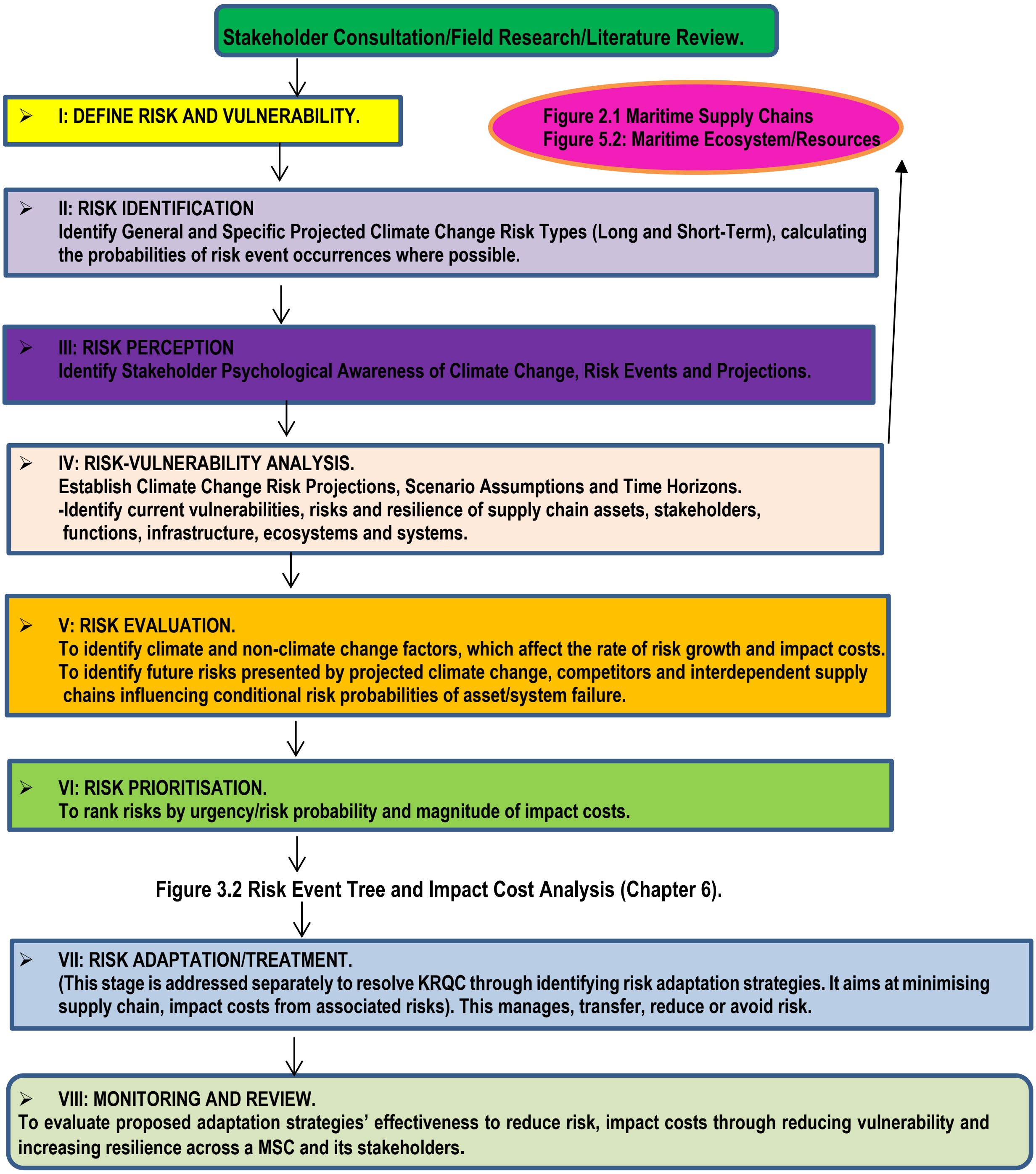
This chapter method and Figure 3.3 proposes a risk-vulnerability evaluation process during a MSC disruption for stakeholders, standardised across climate change scenarios, emissions growth rate and time horizons. This is capable of identifying risks autonomously of stakeholder, supply chain and company type, size, location, resources and number. It evaluates systematic and individual implications of a projected increase in the frequency, duration and intensity of events on supply chain risk. It aims at effective adaptation. It targets achieving stakeholder requirements identified in Chapter 2. It considers vulnerability, resilience and adaptive capacity. This method aims to aid stakeholders to adjust to uncertainty conditions among projected risks. This creates a dynamic method framework and criteria; allowing information, risks, time, demographics, adaptive capacity, resilience, vulnerability and ecosystems to change. With empirical, impact cost estimates, this method emphasises the significant, direct and personal cost, consequences of ignoring climate change. Unlike others, it enables environmental sustainability; improved technical efficiency, training and maximised opportunities across Pacific MSCs. This aims for a world that retains functioning, cost-competitive supply chains and the physical survival of maritime economies with highly vulnerable, coastal communities.

3.3.4 Theoretical Framework Method Stages for Risk-Vulnerability Analysis.

To identify risks for stakeholders across Pacific MSC stages (KRQA), the proposed risk-vulnerability analysis method includes 7 stages in Figure 3.3. This thesis emphasises creating a new risk perception stage (III). This ascertains stakeholder awareness of risks, when compared to actual data; to evaluate their psychological capacity to accurately determine, value and understand risks sufficiently. Given risk perception bias, this stage is proposed to consider the extent to which stakeholder awareness is measured accurately. This minimises risk omission, under and overestimation. It advises stakeholder identification of past risk frequency, duration and intensity/impact costs. This can be combined with asset failure against existing risk events, to provide objective, risk identification criteria. Once risks are identified and combined with projected impact costs and calculated through the proposed impact cost analysis in section 3.5, stakeholders may more effectively establish stage VI (risk adaptation and treatment). As Section 2.7 highlights an effective risk assessment framework would integrate mitigation, adaptation, retreat/surrender, relocation and ecological rehabilitation. Stage VII advocates prioritising risks with potentially more urgent or significant impact costs.

Each stage substantially differs from the FSA conceptual framework (Section 3.3) and other risk management frameworks yet to be adapted to climate change; through its links to MSCs and ecosystems. This framework ignores interconnected, indirect/direct impact costs in Figure 3.2. This sequence also recommends a final monitoring and evaluation stage VIII. Virtually no post-impact adaptation, feasibility studies exist for climate change, risk management including supply chain stages. This stage needs repeating to prepare stakeholders to continuously identify emergent risks, over future time horizons, as risks fluctuate in duration, intensity, frequency and impact costs. It is also necessary to assess each adaptation strategy's value through the extent to which it resolves key risks and associated impact costs, whilst preserving stakeholder requirements. This is ignored by Figure 3.1 and other existing risk models.

Figure 3.3: Proposed Vulnerability-Risk, Analysis Stages For A MSC.



Source: Author.

3.4: RESEARCH DESIGN: INTERVIEWS/SURVEY QUESTIONS (STAGE I):

Previous climate change, impact studies for ports outlined in Chapter 2 identify several advantages to a semi-structured interview/survey method approach with key stakeholders for data collection (Becker *et al.* 2011; McEvoy *et al.* 2013; Scott *et al.* 2013). As previous research has not been undertaken on this thesis topic, field research is necessary to acquire primary data. A lack of relevant secondary data with locational/situational specific information applying to individual Pacific MSC case studies exists. This also assists to ascertain the extent of climate change awareness, and adaptation for Pacific nations. It facilitates analysis of potential solutions that may apply to other regions threatened by similar risks. Local risk, impact cost and other information identification aids in risk prioritisation and incentives to cooperate across a MSC. Attention can then be directed to more urgent risks, minimising supply chain congestion, delay and other disruption impact costs, wherever possible. It reduces reliance on external parties.

3.4.1: Research Questions

These research questions are developed in section 1.3 and justified in a systematic, literature review (Chapter 2) and pre-testing (section 3.3.2). They are specifically included in the survey in Appendix V, to affirm this multistage, research method. Given time, fiscal and other research study/developing nation constraints including scarce resources; these questions and their modified survey equivalents are few.

KRQA: What are the current and projected risks for Pacific Island, MSCs from climate change consequences?

KRQB: What is projected to be the economic impact costs of climate change on the future of Pacific Island MSCs and for a specific commodity?

KRQC: How can key supply chain stakeholders adapt to minimise the impact of climate change on Pacific Island MSCs?

ARQI: What are the specific constraints/barriers to developing adaptation strategies for climate change?

ARQII: What are possible solutions to adapting MSCs to climate change in the Pacific Islands?

3.4.2: Questionnaire Pre-Testing Process and Design

The survey/interview questionnaire, invitation letter, informed consent form and reminder email in Appendices I-IV were pre-tested to enable a generic, sampling strategy response. These tested ethical considerations, research design feasibility, strength reliability, accuracy and clarity, grammar, spelling, style, structure, question relevance and minimising sample bias, systematic and random errors. The pretesting survey faced peer reviewed bias and error control. It was submitted to PhD students, AMC academics, Tasmania Research Ethics and Cook Islands Ethics Review Committee and general MSC stakeholders. Sarantakos (2005) and Fei (2009) consider a pre-testing sample of 10-30 from experienced professionals sufficiently identifies structural concerns to avoid double counting and systematic errors. The question design has been peer reviewed to ensure relevance, coherence along with included ethical considerations. Questions are focused, structured and practically feasible. This includes simplifying questions, avoiding ambiguity, testing for any question omissions and existence of superfluous questions. The survey was modified where pre-testing perceived it as necessary to improve it to be sufficiently understood by Pacific MSC participants.

Pre-testing determines whether this data collection method represents a pragmatic, effective mechanism to resolve key research questions (World Bank, GFDRR and USAID 2015). The question design is based on pre-coded, fixed choice options from the risks, impact costs and adaptation solutions identified in existing literature and previous chapters. This ensures specific relevance towards this thesis's research questions. It identifies the risks, direct and indirect impact costs identified for stakeholders in Figures 3.2 and 3.3. It identifies adaptation solutions for Figure 3.5. However, the survey/interviews contain open-ended questions to actively stimulate, local stakeholder participation. Providing a range of broad, pre-defined, question choices concentrates stakeholder perceptions on the most relevant, specific and pivotal factors, given research constraints. Constraints include stakeholder requirements, limited resources, funding capacity, legal issues, informational availability, extent of cooperation; experience; concerns and awareness of climate change on Pacific MSCs. The survey/interview questions are specifically included and designed towards understanding climate change's, projected economic impact for Pacific MSCs. These are partially devised from time series data and survey questions 1-4. Equation 3.1 can be determined from survey questions 4/5. Impact costs are indirectly calculated from questions 4 and 5, by combining individual result calculations. Interview questions are designed to expand beyond survey questions, providing greater context. Therefore, these interview questions in Appendix I will be addressed to key Pacific stakeholders as method Stage I.

3.4.3 Justifying Specific Pacific Research Case Study Locations

As Chapter 2 observes, a case study methodology approach is constrained by time, financial budget, resources and other significant research constraints. From 17 Pacific Island nations for Chapters 5-7, it specifically applied the proposed methodology to one Cook Islands, case study. Specific climate change projections are highlighted in Chapter 4. This is selected as a location for field research for reasons of transport accessibility; cost, previous climate change research, data, time and stakeholder contact information availability. It offers greater physical vulnerability to risks along with divergences in disruption risks, impact costs and adaptation solutions. This country is also politically stable, minimising field investigator risk. It has decades of project experience in climate change adaptation and disaster risk reduction including surveys, with significant risk awareness campaigns by researchers and NGOs. Kaiteie and Hogan (2008) consider climate and risk exposure divergences across several Pacific Islands, further improves a conceptual framework's validity and structural robustness. Section 2.7 identified various advantages to using Pacific MSCs, with a smaller sample pool. These avoid outsourcing and offer limited customs, trade and beneficiation stages, simplifying data collection and empirical, impact cost analysis.

The Cook Islands has just completed climateproofing of Aviatu/Mangaia Harbour to provide a case study of actual climate change adaptation for ports. It had the research benefit of responding to initial contacts. Australia and New Zealand were excluded as developed countries with considerable resources to adapt. Tuvalu, Nauru, Niue, Palau, the Marshall Islands and other Pacific nations were primarily excluded as being remote, economically peripheral, even lacking a functioning port authority website. Several lacked sufficient stakeholder contacts or possessed myriad similarities in projected risks and adaptation strategies. Therefore, this research represents a conceptual point of departure, in evaluating these impacts for Pacific MSCs. It offers case studies that are comparable, relevant, concise, specific, consistent, have information and cooperative stakeholders. This research retains certain economic significance for global stakeholders, which depend upon these supply chains.

3.4.4: Sampling Strategy/Identifying Potential Respondent Stakeholders

A MSC stakeholder is defined in Figure 2.1. Participants are assessed through initial questions and stratified sampling selection (Bouma and Ling 2006; Frankfort-Nachmias and Nachmias 2007; Bryman 2012) to indicate whether they are a stakeholder. More detail is provided in Appendix I-V. Consulting these experienced stakeholders aware of climate change, in stratified sampling, selects stakeholders from specific supply chain stages over random population sampling. This aims to improve the interview response rate, quality, accuracy of data and validity to subsequent stakeholders (Aggarwal *et al.* 2011; McNamara, Hemstock and Holland 2013). To establish an effective respondent, snowballing, sampling strategy; recruitment utilised a combination of networking at specialist conferences/contacts in Appendix VIII (research output). It uses direct, publicly available websites (principally the major seaport as the major MSC stage affected), secondary data contact information and a polite request to various Pacific agencies//associations. This request enquired if the invitation, survey and consent form is circulated to relevant supply chain contacts. Contacts can voluntarily choose to participate/disclose contact details, to protect confidentiality.

The sample strategy is primarily based around supply chain producers, seaport authorities, government, intermodal transport and other commercial participants. They are capable of offering an informed perspective and will be directly affected by climate change on a MSC. This is based on limited information availability and sample poll with few Pacific MSC stakeholders, as regular users of Cook Islands and

Pacific main ports with accessible contact details. Demographics are not expected to influence thesis results. The research justification for the stratified, participant sample included only a few existing, pertinent MSC stakeholders who are prepared to respond. It also considers if questions are relevant to specific, research objectives and compatible with the case study, data availability and existing sources, suggested by Jira and Toffel (2012).

3.4.5: Data Collection Methods

Primary data collection is acquired through field research with direct stakeholder consultation, semi-structured interviews, to establish method and data analysis in Stages II-IV. The researcher submitted a stakeholder interview, introduction letter, distributed via email and in person, where necessary. This invited the respondent to participate (Appendix I/III) by signing the informed consent form (Appendix II/IV) and completing the survey/interview (Appendix IV). Approximately 1 and 2 weeks later, polite reminder emails will be sent to any respondent who have not submitted forms/responses (Appendix VI). This encouraged responses by emphasising the research value and their participation. Secondary data was obtained from physical and electronic sources. Where necessary, follow-up visits to collect data results/conduct interviews are undertaken to improve participant, response rates. Participants also indicated a preference for open-ended questions, which they personally contribute. This improved the response rate.

3.4.6: Data Management and Storage

All research data is securely stored in a safe University location at the Australia Maritime College, Launceston Campus for a minimum five years until being destroyed. This adheres to the 2007 Australian Code for the Responsible Conduct of Research, section 2.1 and the University of Tasmania, Data Management Guidelines, section 4.3. Only aggregated, non-identifiable data from which personal details/perspectives are removed; will be publicly published and disseminated except with participant stakeholders' signed permission and informed consent. All physical data is locked in a filing cabinet, all-electronic data in a University secure, password protected computer, in a safe location. Only researchers involved in the study will have access. Data is backed up through a secure online UTAS Cloud service and working copies on password-protected flash drives. To maintain file integrity, these are not used on public computers with unrestricted access.

3.4.7: Ethical Considerations and Risk Management

No direct physical, personal, legal, environmental, social, cultural, political, technical, operation or financial risks were envisioned to participants. However, undertaking any research involving human participants at the University of Tasmania or any other Australian university requires reassurances ethical issues have been considered to protect respondent rights. This research complies with section 1 of the 2007, National Statement on Ethical Conduct for Human Research to protect research integrity, ensure merit and respect for participants by identifying risks. This thesis undertook full peer-reviewed interview pre-testing and confirmation of candidature presentations. It received ethical clearance approval from the Tasmania, Social Sciences, Human Research, Ethics and the Cook Islands, Ethics Review Committees (Appendixes VI/VII). It specifically outlined how any projected ethical consideration will be addressed in Appendixes I-V. These include the confidentiality and anonymity of participants from foreign countries and other rights and risks including commercially sensitive data. The statement's section 2.2 requires sufficient information granted to participants to enable an adequate understanding. A free choice to participate or withdraw was made clear on the form. Participants were given a month's notice, and 4-5 weeks to decide to participate in the interview. Reminders were submitted over several weeks, to indicate availability for an interview over the next 2-3 months. Access to confidential or commercially sensitive to information is anticipated in calculating supply chain, economic impact costs but only with participants' prior consent. Risks are reduced in referring to past risk events and confidential, secure results. Participants are further protected, being notified verbally and via specific invitation, reminder and informed consent forms (Appendixes I-IV) of their rights. Contact information is provided if they have any research concerns to the investigator and committee. They can withdraw at any time and their data can only be utilised with formal signed consent.

To consider participants' rights in other countries under the 2007 Statement (section 4.8); this research undertook a separate Cook Islands ethics review application, as the researcher could not locate equivalents for other locations. All data collected is treated in the strictest confidence, aggregated and made non-identifiable with personal contact details removed. It is securely stored and managed (section 5.3.5) to further protect specific rights prior to publication/dissemination. Participants will be also offered the chance to review the aggregated results once personal identification has been erased. There are no ethical considerations or risks expected for other research stages. These involve data analysis, with no human interaction or need to be based outside the Launceston university campus or Australia. The investigator not the participants/University bore the fiscal costs and risks that may develop through field research. From a risk management perspective, a slight, personal risk element occurs from conducting field research in foreign/Pacific countries. These might be susceptible to natural disasters, social, climate and economic/political instability as developing nations. However, this researcher notes the historic stability of Cook Islands, along with Pacific stakeholder experience for generalised, climate change research projects. It articulates how various issues/risks was resolved in the attached approved Cook Islands and Tasmania, Ethics Committee applications. This researcher has extensive travel experience on 5 continents over many years; has conducted similar survey field research on 3 continents and lived/educated in Africa, Europe and Oceania. Any adverse event or unexpected development affecting this research was formally reported to Ethics Committees, with an explanation wherever possible to minimise risk.

3.4.8: Monitoring, Bias and Error Control

To reduce potential sources of bias, ensure error control, ethical considerations and research quality, this thesis undertook several monitoring procedures for quality assurance. These monitoring procedures include regular scheduled meetings with PhD supervisors, an academic peer-reviewed Confirmation of Candidature and subsequent annual Reviews of Progress. It includes the ethics application process (Appendix I-V) and annual and final reports noting any specific issues that may occur throughout all research stages. The interview schedule/survey was also subject to peer review, pre-testing, providing a further source of bias and error control. The process revealed the need to reduce ambiguous or double-barrelled questions, provide sufficient answer space, simplify questions and provide more explicit, concise, relevant information as suggestions. These were adopted to improve the stakeholder participation rate.

Respondents will be offered the explicit choice of ensuring errors are controlled and minimised able to review aggregated, non-identifiable data results, prior to thesis submission and identification. This reduces issues of selective recall/subjective awareness of events. Personal interviews can aid clear response articulation. Any participant who withdraws at any stage and indicates that withdrawal, will have their results removed from the study and accumulated data destroyed. However, stakeholders may communicate with each other, given normal, interactive proximity to conduct business. These might inadvertently refer to the interview, research process as a source of bias, (though not from the research investigator). Often issues of omitted variable, spurious, regression correlation, random and systematic sampling error and survey bias exist. This occurs where the way it is framed/presented can alter the response (Schuldt, Roh and Schwarz, 2015).

To reduce response bias, the interviewer/all appendix sheets adopts neutral, unemotive language and tones, not revealing personal preferences but clearly establishing a range of study-related, fixed choices. It also allows open-ended responses to endorse stakeholder participation. Certain participants preferred open-ended questions, which they can contribute more personally relevant perspectives. Given potential sensitivity over climate change, the study and research methodology concentrate on specific risks, impact costs, constraints and solutions to marine resources. This presents as a key MSC commodity, rather than communities covered in previous studies (Kaiteie and Hogan 2008; Dumaru *et al* 2011; SPC 2013b). It avoids subjective judgements or perspectives, emphasising anonymity to facilitate research candour. It provided a thesis established source of related risks, impact cost types and adaptation solutions. This prevents over-demanding recall, with sufficient time warning/opportunity in advanced notice to establish solutions. It offered stakeholders the choice to identify others the researcher had not considered to improve results. However, past training/experience of climate risks might alter perspectives and responses significantly. A positive response bias aims to be minimised through third party verification; calculated impact cost analysis and field research. This ascertains direct vulnerabilities, risks, costs, constraints and degree of proposed adaptation strategy effectiveness. It can be confirmed through other stakeholders, indirectly checking response data for further validity with stakeholders prior to submission.

For this thesis, several factors may influence the nature of and limit stakeholder participation rates including asking for potentially commercially sensitive cost information. Adaptation strategies may lack attention or resource priorities. Power may be located at headquarters with little or no local autonomy to influence policy responses. Insufficient data may exist. Interviews may be unpopular in taking scarce time, (although to incentivise participation; a free research copy was offered.) Projected climate change uncertainty and inconsistency in existing research prompts moral hazard and risk averse stakeholders. For small Pacific nations exceeding 30 years of climate change adaptation a risk of over-information and exposure exists, combined with aid dependency reducing autonomous initiative. Stakeholders can tire of the same questions repeated. This risk occurs when existing aid agencies/researchers do not consult previous research in consultation and in proposing adaptation project solutions.

3.5: ANALYTICAL FRAMEWORK:

3.5.1: Analytical Framework: Probability of a Historic/Future Climate Change Risk/Conditional Probability of a MSC Asset/System Failure and Factors Affecting Risks

Section 3.2's evaluation of existing, quantitative method studies established the Poisson distribution over alternatives. This establishes the foundations of the following, analytical risk framework for general and

MSCs. It validates the above conceptual method, through identifying and defining risks. This framework considers climate change and non-climate factors that influence the probability of a risk occurrence, the scenario and time horizon through Figure 3.2. Specific scenarios and time horizons are verified scientifically through the IPCC reports. Climate data is independently and consistently established by the SPC, SPREP and Australia's CSIRO. The proposed research method will incorporate the probabilities of a projected risk occurrence, combined with its impact cost consequences across Pacific MSCs. An absence of suitable alternative methods, equations, studies with specific probabilities and theory for effective risk management was established in Chapters 2/3.2. Without established equations to estimate climate change risks using specific probability distributions, section 3.2 previously justified the Poisson distribution for Equation 3.1. This applies the average probability of a past risk event occurring to a historic, Pacific risk event. This method proposes its contribution to risk management theory to calculate the average, independent probability of a specific and short term, risk event in Appendices. It advances an equation and framework integrating the risk type, its probability of occurrence, past data, potential accumulative risk, an event's frequency and duration.

Probability of a Historic Pacific, Climate Change Risk Event Occurring.

Although current studies have not specifically applied risk probability theory to projecting future climate change risk; this thesis's theoretical contribution proposes adapting basic distribution/equations to form equation 3.1 (Section 3.2). This method and Chapter 4 Pacific Futures tool, climate change projection techniques and screening criteria enable future event probability calculations. It considers the probability of a future risk event, not only needs to evaluate past risk events but changes in time, rather than remaining static. It must incorporate accumulating risk and the joint probability of 2 or more risk interactions (when such events occur); given climate change is fundamentally dynamic. To resolve problems of selective recall and limited information, the method proposes emphasising recent, past events for which stakeholder data potentially exists. This estimates expected average number of risk events per year given historical, actual events and future projected increases in frequency/probability of occurrence. These are adjusted for increased, accumulating risks per year to calculate future probabilities.

Unlike previous probabilities assuming the status quo remains over an event or asset's lifetime, this framework considers risk events as fundamentally dynamic rather than static (merely reliant on historic time series data, given uncertainty and climate change). These include increases in yearly, accumulative, Pacific risk. An interaction or joint probability is necessary for calculating certain related events. For example, this includes the historical correlation between storms and flooding; tsunamis and landslides;

precipitation, SST, wind velocity and cyclones; earthquakes and volcanoes simultaneously. This method provides flexibility across time horizons, supply chain stakeholders and climate change scenarios. Event probabilities, the degree of confidence and significance of results are adjustable based on available and simulated data.

This framework will assist policy stakeholders to understand personal impact costs and across supply chains, as they possess very few research examples of specific costs. As a pioneering method for climate change, risk management for MSCs; method provide research advantages as per the Appendices. It is adaptable to divergent risks, asset types, scenarios, stakeholders and stages. It can incorporate resilience, vulnerability, accumulated risk and factors affecting the probability of risk occurrence and adaptation costs. This method details how risks diverge across individual specific MSCs for Pacific, small island, developing states. It aims to be sufficiently robust to overcome challenges of risk double counting, underestimation/overestimation, subjective stakeholders' risk perceptions and factoring past, present and future risks. These risks may influence each other as risk interdependencies. This thesis's contribution to above, existing literature methods is to consider how risks and impact costs can also vary across countries, economic sectors and stakeholders. These differ from experience, education, climates, environments, asset properties and stakeholder willingness/capacity to pay and adapt.

Previous risk management methods are mostly restricted to average events and the normal Gaussian distribution, including Formal Safety Assessment. These methods also use stakeholder perceptions to qualitatively measure risk. They do not standardise risk definitions or quantifying probability criteria. Events are seldom independent, conditional upon recent/past factors. This thesis follows statistical outliers in its distribution (Mandelbrot sets), based on projected, climate change simulations. It also incorporates original, empirical and field data. Its criteria are independently evaluated and established where possible. It utilises time series data to convert the probability of a low probability, high impact, Black Swan event into more frequent events. The principle concern of Pacific MSC stakeholders is asymmetrical information. They might not know of, or agree with available information sources, the probability of an asset failure or the criteria used to measure failure (i.e. cost/ performance/ sustainability). They may be unaware of how to calculate general and conditional probability. They may not possess criteria to determine resilience, vulnerability and adaptive capacity to quantify probability. This thesis's conceptual contribution provides criteria in Figure 3.4. These criteria convert these factors into information for stakeholder requirements and functions. This risk estimation approach needs to indicate the probability of an asset/system failure. It identifies which risks to prioritise and why. It identifies when and where to prioritise this risk. These criteria then assist in calculating historic, current and future impact costs as potential consequences.

Figure 3.4: Key Variables for Climateproofing Against Risks

Stakeholder Criteria in Evaluating Which Risks to Prioritise and Why?

- Probability of Climate Change Risk Occurrence/Conditional Probability of Asset Failure.
- Size of Impact Costs/Consequences.
- Resources available.
- Historic, Current and Future Risk.
- Factors affecting asset condition, resilience and vulnerability.
- Physical Location. Time Horizon; Climate Change Scenario.
- Stakeholder Requirements.
- Other Supply Chain Stakeholders.
- Competitors.
- Capacity for Redundancy.
- Extent of supply chain interdependent and exposure
- Contractual obligations.
- Legislation/policy guidelines.
- Fiscal/donor funding incentives/disincentives.
- Potential for research innovation/technical progress.
- Changes in demographics/migration, tax and legislative policy.
- Identify Physical environment and risk factors.
- Identifying accumulative impacts from past and current events.
- Updated communication/information systems and sources.
- Physical changes in species/ecosystems/climate.
- Resources available and other adaptation constraints.
- The extent and effectiveness of mitigation/adaptation as factors potentially affecting the extent/probability of risk.

Thesis Criteria to Evaluate Stakeholder Asset Condition for Probability of Risk Failure.

- Physical location/risk exposure/vulnerability.
- Recovery Time to Disruption Risk Event.
- Performance, productivity and output metrics.
- Efficiency –through cost minimisation and optimal resource allocation.
- Frequency of Maintenance.
- Asset age.
- Asset Materials/Properties.
- Technical Standards.
- Ecological Sustainability.

The method incorporates these Figure 3.4 factors to improve accurate risk identification, estimation, analysis and prioritisation for MSC assets. These criteria integrate systematic and individual uncertainty. This method proposes utilising IPCC scenarios, time horizons and probabilities plus tools including Pacific Climate Change Futures and PCARFI. These offer techniques to adapt and customise more specific probabilities. It also creates more objective criteria for stakeholders to consider performance and probability of failure for both climate change and other risk disruptions. It provides a developing world and commercial, context in contrast to myriad existing adaptation and risk management, case studies.

3.5.2: Economic Impact Cost, Data Analysis Method, Framework for a Pacific MSC (STAGE III)

Section 3.2 identified significant research gaps in existing climate change, impact analysis. Many previous methods detail only qualitative descriptions of impacts. These seldom provide specific and actual cost estimates via field research or stakeholder consultation. This section therefore extends the Figure 3.2 event tree and conceptual framework to impact cost analysis. This analytical framework includes time horizons and climate change scenarios (3.5.3), equation and model assumptions (3.5.4) based on certain methodology limits (3.5.5). This approach has not been previously applied across an entire supply chain for all stakeholders, commodities, risk event types, impact costs and scenarios. Providing a combined method (simulation, qualitative and quantitative) enables stakeholders to avoid underestimating event disruption costs. It emphasizes the need to adapt to potential risks. This model aims to determine and evaluate direct, economic impact costs of projected risks for maritime resources as a specific commodity, across Pacific MSC stages. Based on time and fiscal constraints, this thesis restricts this method to direct/indirect disruption costs that can be estimated for a specific commodity. These are estimated at each stage, as a projection of total supply chain damage. This provides Stage III, after data obtained in Stage I. Stage II proposes an integrated model, after establishing a risk-vulnerability analysis of key Pacific MSC asset exposure to projected risks. This influences potential impact costs (Stage III).

3.5.3: Time Horizons and Climate Change Scenarios

Chapter 4 provides the Pacific, Climate Change, Futures tool to achieve downscaled Pacific data, adjusted for different climate change scenarios and time horizons. This thesis follows the IPCC (2015) conventional three, time horizons of 2030 (short term), 2055 (medium) and 2100 (long term adaptation. This considers long-term risks when including equation variables that include asset lifecycle value and replacement costs as fixed across time periods. Sudden, short-term risks vary between seconds to a year in duration and impact cost consequences depending on the extent of direct costs involved. Studies generally agree the longer the time horizon included; the higher the projected impact costs (CSR 2011; Johnson, Bell and DeYoung 2012; BSR 2015). While previous studies focus on long-term costs, short-term impact cost analysis can be more useful to MSC stakeholders to ensure business continuity. Climate change mitigation and adaptation with planning horizons is generally calculated in months, a year or up to 5 years. For climate change it will be calculated over decades. The proposed data analysis incorporates impact cost variables, based on estimated monetary, market value and year values to simplify calculating direct costs. This offers the potential to discount impacts over future years, (although indirect costs can exceed decades).

3.5.4: Impact Cost Analysis, Analytical Framework and Methodology Assumptions

This thesis proposes an econometric model capable of identifying projected economic impact costs of climate change, disruption risks upon a specific commodity in Figure 3.2. This model extends across an entire Pacific MSC for all stakeholders and stages. A conceptual framework methodology should be robust and valid for inclusion and applicable to its Key Research Questions. It needs to overcome or improve upon previously identified literature gaps. An economic impact cost analysis method for supply chains should justify/consider time horizons, projected climate change scenarios and the interest/discount rates over time used. It requires specific variable inclusion, data availability, data collection, data analysis and data management, overcoming econometric issues, as covered in various sections. It must detail any potential ethical issues. The method needs to consider direct economic, impact costs of climate change inaction compared to adaptation costs. These costs need to be analysed for combined long and short-term risks for a specific commodity across different Pacific country examples and supply chain stakeholders. It must consider reasons for divergences in results. The number of Pacific countries to use, any regression tests and statistical analysis to perform be included and its applicability to the context of Pacific and global ports, shipping and MSCs inserted. It needs to be justified as this study's conceptual contribution to impact analysis methods for supply chains. It should consider the most effective methodology to address its research objectives across divergent supply chains; without any past literature identified method sufficiently resolving the above issues. It must be generalisable to other global examples to be of further research significance (Hansel, deJager and Neelis 2014).

To propose this econometric model, this method is based on the following assumptions to adjust simple, impact cost analysis to climate change risks for MSCs. It provides a thesis-derived equation to determine historical impact costs for stakeholders. The sample size or number of observations is determined by data availability and respondent cooperation. To calculate a supply chain's net economic impact or present value for a specific commodity under climate change; this method proposes costs can be calculated and summarised for each stakeholder (TB−TC). These can then be aggregated for all respondents to estimate an entire supply chain's impact, based on existing market values. Each regression includes a constant Co and structural error term Et to reduce model misspecification errors. It includes changes in time period values Δt for each impact cost duration. The net value/contribution or average daily, economic impact cost of a commodity across a Pacific supply chain = Climate Change Economic Impact Costs to supply chains. If risk events occur, estimates are calculated by adding benefits and subtracting impact costs summarised below.

Climate Change Economic Impact Cost Estimations for a Pacific MSC (HCCREIC)

The following shows how the net climate change economic impact cost for a Pacific MSC (CCEIC) can be estimated:

$$\text{HCCREIC} = C_0 + \sum \Delta t\,(TB - TC) = \sum j \sum_{k=1}^{n} y jk + Et \qquad \text{(Equation 3.4)}$$

Where: Let C_0 = Constant.

TB = Total Impact Benefit. TC = Total Impact/Infrastructure+ lifecycle replacement Cost for y_n; $y_{j1} - y_{jn}$ = Impact Costs summarised below for which data exists. Where j = accumulated lifecycle costs. Δt = Change in time period.

Source: Author

Each identified impact cost, MSC stage and risk event can be combined for data analysis obtained from primary data collection. To calculate economic, impact costs directly linked to a sudden risk aftermath, the method uses averages for a commodity's adjusted, current, market value. The model equation can also be flexibly adjusted to calculate a supply chain stakeholder's specific impact/value. This summarises personal impact costs across all stages, without aggregating other costs. For example, for total port throughput, daily impact cost would be divided by 365 days the supply chain is accessible, to disaggregate data to multiply it for a specific event, economic impact cost. Each impact cost for which data is obtainable for Pacific, small island, developing states/MSCs can be determined individually and aggregated for all stakeholders within each stage. It is calculable and aggregated across an entire supply chain. These impact costs will be determined from survey question 5 (Appendix III) and Appendix IX.

These summarised variable types represent direct impact costs identified in Figure 3.2 (orange). These were located from a systematic, literature review and stakeholder consultation via field research. The variables have not been previously incorporated into any past study method, calculated or specifically applied to global/Pacific MSCs. This presents this thesis's, analytical framework and data collection, contribution. These impact cost magnitudes are influenced by existing risk factors (pink Figure 3.2). These are identified through the risk and vulnerability framework in section 3.4. These factors include local resilience via ecosystem protection, training and experience, existing and future adaptation constraints. They incorporate the extent to which adaptation has been previously and subsequently prioritised (3.4.3) or undertaken. Factors directly affecting impact costs are summarised in the Figure 3.2 outlined conceptual framework. These include market power, experience and degree of cooperation/information sharing with other MSCs (Australian Department of Environment and Heritage, Greenhouse Office 2006; Sawyer 2014; Krey *et al.* 2014.)

This method proposes impact costs can be calculated and adjusted from equation 3.4 and summarised for each stakeholder based on past, current and future risk events. The model focuses on event specific, disruption costs, in determining coefficient estimates to be included over time. It can incorporate panel data specifically applicable to other Pacific, supply chain locations, stakeholders, stages, impact costs and/or additional risk events. It can be restricted to direct, indirect and/or intangible impact costs for stakeholders. Being fixed these costs are stabilised for potential rates of depreciation, inflation and exchange rate fluctuation. Costs are calculated in US currency values. This is considered the most accepted, exchanged international currency and one for which information is internationally consistently available.

This thesis proposes lifecycle asset replacement cost includes fixed asset, lifecycle values based on long-term risks i.e. SLR, precipitation, ocean acidification and temperature changes. These affect an asset's exposure to climate change over a significant time horizon. Each supply chain stage can be aggregated to provide a specific event's, total economic impact and discounted over future periods. As a possible, future research area, this approach could calculate indirect, impact costs of specific risk events. Existing studies ignore climate change, accumulated impacts, discounted across future time horizons. These methods ignore specific risks, costs and innate resilience/adaptation capacity may differ across countries in duration, frequency, intensity and probability of occurrence. This method resolves this, applied to a specific Pacific nation's global MSC as a case study in Chapter 6.

3.5.5: Limitations

This thesis methodology is subject to certain model limitations. This study is exploratory in nature and the approach is based on a holistic view for managerial reference and implication, rather than theoretic view, which was not the thesis' primary focus. These limitations exist from the significant lack of previous related studies, adapted methods and incomplete data available. Previous studies do not apply holistic, integrated models across different Pacific countries, stakeholders, risk types, commodities, time horizons, scenarios and across an entire supply chain system from producer to consumer as in Figure 3.2. Climate change uncertainty presents the greatest research limits, over its probability of occurrence, frequency, rate of growth, duration, and associated likelihood/impact consequences for various risks. Past approaches have limited direct value, given subjective, risk perceptions over probability of occurrence, risk types and valuing impact cost for assets. These affect omitted variable bias and model misspecification errors/various econometric issues. They are further influenced by which regression tests are utilised, to improve model robustness. Not all impact costs ascertained are directly quantifiable and monetised i.e. net economic value of human lives lost; a collapsing local economy and ecosystem cost. Where data is omitted or restricted as commercially sensitive, this creates problems when calculating specific impact cost estimates. These impact cost and benefit values remain conditional on projected inputs selected, the method utilised, different time horizons, discount rate utilised; number of consulted stakeholders and rates of climate change growth for various Pacific scenarios. Certain costs and benefits may affect multiple stakeholders. This produces major potential impact overestimation or underestimation.

Other analytical framework limitations include assigning and calculating an impact cost value. This forms another challenge to creating a climate change, impact cost analysis model, method and theoretical framework. This value is complex to calculate, based on opportunity cost for economic activity that did not occur, as a direct risk consequence. Its calculation is further complicated in calculating maladaptation and vulnerability/resilience costs over an asset's potential lifespan. Current research lacks consistent methods of comparing risks across different asset functions and design standards (Anthoff, Nicholls and Tol 2010, Ng *et al.* 2017). Most supply chain stakeholders plan separately without information sharing, multiplying projected impact costs. They may possess different cost methodologies and data. Previous studies often ignore this problem when suggesting impact costs can be computed. Using a single investigator and direct stakeholder consultation for field research provides greater consistency. When focusing on adaptation; more accurate impact costs can be obtained from the extent to which it improves net future economic value via supply chain performance improvements. This thesis also recognises the complexities of isolating impact costs specifically associated with climate change risks from other established risk types e.g. port strikes. Any impact cost finally depends upon stakeholders' psychology, expectations and the actual event occurrence.

3.6: IDENTIFYING CONSTRAINTS TO CLIMATE CHANGE ADAPTATION AND ADAPTATION RESPONSE STRATEGIES (STAGE IV)

To address KRQC, ARQI and ARQII in Chapter 7, this section outlines the integrated methodology's final stage IV. Unlike previous adaptation studies, it identifies stakeholders' adaptive capacity across an entire MSC system (Becker 2014; Yang *et al* 2015; Ng *et al* 2017). It does not restrict this for individual stakeholders and operations. It advocates a method for identifying and evaluating existing constraints to climate change, adaptation and the effectiveness of historic and current, adaptation solutions. It determines stakeholders should adapt if an adaptation measure or strategy's benefits to minimise impact costs exceed potential costs. Cost-benefit analysis is applied to establish the costs and benefits of a risk's impact costs with and without adaptation responses. This quantifies accurate direct, indirect and intangible costs.

This model can measure impacts for individual stakeholders and stages and across an entire supply chain system. It is generalisable to global and individual examples. It proposes separate impact cost analyses for each specific location or Pacific Island nation. Differing risks, impact costs and consequences along with the extent of existing ecosystem, infrastructure and human resilience, previous experience and resources, justifies disaggregated, country specific data. To calculate impact costs, the method proposes adding the benefits or next present value retained to the regression; if adaptation was successful and prioritised to impact costs. It subtracts adaptation costs, for each stakeholder and stage to minimise risks. Adaptation calculations should consider factors outlined in Figure 3.2, given climate change uncertainty.

This thesis includes a final risk monitoring and evaluation stage for any proposed solution so it is consistently updated as risks emerge. This stage is necessary to continuously aid stakeholders to consider which supply chain locations, equipment, resources, labour and technology are most at risk. It is effective in locating which assets are most necessary for an efficient, swift, cost-effective and environmentally sustainable Pacific maritime and global supply chain. This method approach aims to provide a theoretical framework of coordinated, adaptation strategies. It further benefits MSC stakeholders with limited resources and other constraints, to facilitate capacity building. This seeks to reduce climate change, consequences for supply chain performance, capacity and utilisation; including lower resilience, increased vulnerability, risk exposure and estimated impact costs.

3.6.1: Existing Constraints to Climate Change Adaptation

To identify existing climate change adaptation constraints, this method uses data from survey Questions 7-10, peer-reviewed literature, experience and stakeholder consultation. It answers questions and constraint types outlined in Section 3.1.3. These constraints include asymmetric and insufficient information, land, geophysical, labour, capital, economic, transport, environmental, information, communication, social and cultural factors. They include the uncertainty of climate change projections. Other constraints include psychological, legal, political, technological, education, administrative, planning, coordination and stakeholder cooperation factors (Messner *et al* 2013; USP 2013; Wang 2015). Summarising short, medium and long-term constraints enables affected stakeholders to form site, individual and supply chain specific barriers over time. Providing criteria targets adaptation strategies more swiftly, accurately and efficiently; whether pre-event, during a risk event or post-event. These need to be effective, environmentally sustainable and answer stakeholder concerns. Swift responses minimise maladaptation and opportunity costs and facilitate co-benefits. These constraints will be evaluated for a Pacific MSC in Chapter 7.

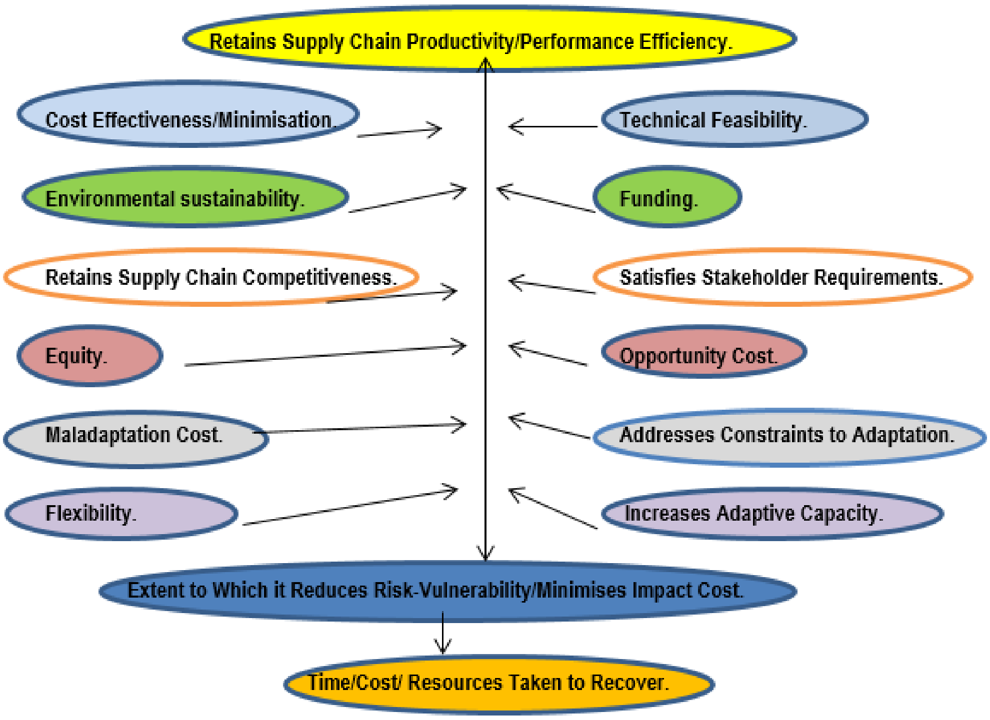
3.6.2: Adaptation Solutions

This final integrated methodology stage proposes to identify and evaluate adaptation solutions for existing and future MSC stakeholders. Its research significance proposes criteria in Figure 3.5. This contrasts with other studies, which ignore existing adaptation efforts, proposing their own solutions. These criteria enable stakeholders to evaluate existing adaptation strategies objectively. These criteria aim to minimise maladaptation costs further, when applied to the integrated, climateproofing, adaptation strategy in Chapter 7. This assists stakeholders with scarce resources and institutional capacity to adapt effectively. General supply chain, adaptation solution types were identified in Chapter 2. They will be applied to effective Pacific adaptation strategies for individual stakeholders and stages in Appendix XI. Criteria advantages consider whether specific MSCs can similarly adapt and if these solutions are generalizable to other global supply chains. Once these criteria determine if previous adaptation has failed or succeeded, then this thesis proposes altering solutions. This would mainstream and integrate additional climateproofing stakeholder solutions to minimise risks and to complement existing stakeholder efforts (UNFCCC 2010; Australian Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education 2013; Walsh *et al.* 2013).

Proposed Integrated Method, for MSC Stakeholders' Adaptation Solutions

I: Establish a Climate Change, Risk-Vulnerability Sequence, Event Tree and Impact Cost Analysis.
II: Establish existing, stakeholder constraints to climate change adaptation.
III: Identify and evaluate the effectiveness of existing and proposed adaptation solutions. This uses cost-benefit analysis, first for individual stakeholders and then the entire supply chain.
IV: Identify and propose new adaptation strategies, (Repeat Stage III)

Figure 3.5: Adaptation Solution/Strategy Evaluation Criteria.



Source: Author.

3.7: SUMMARY

This chapter presents an integrated methodology capable of identifying and estimating projected climate change impact costs, constraints to adaptation and adaptation solutions for Pacific MSCs. It aims to apply to other general, supply chain stakeholders, stages and regions at minimal maladaptation and opportunity cost. This produces a research framework capable of answering KRQs. This responds to literature gaps identified in Chapters 1 and 2 and existing methodology gaps. Stakeholders can use this method to understand unique risk implications for individual operations and across the entire supply chain. This accomplishes greater opportunities for adaptation and survival. Rather than relying on expensive consultants and feasibility studies, this method aims to empower stakeholders directly especially those of Pacific Island and other developing states.

This study's significance aims to assist stakeholders with scarce resources, finite institutional capacity and asymmetrical information over projected climate change uncertainty. It can analyse adaptation solutions' cost-effectiveness including climateproofing. Stakeholders can consider why they should focus on climate change and the most effective response solutions. This method intends to be applicable and replicable across all short and long-term, risk types, scenarios and time horizons, stakeholders, stages, nations, regions and commodities, as a method consistently valid over time. This contrasts with other surveyed impact methods, which incur research disadvantages of being more context specific. This method aims to assist supply chains and dependent stakeholders in understanding significant, inaction costs in failing to prioritise adaptation.

CHAPTER 4: GLOBAL AND PACIFIC CLIMATE CHANGE RISK SCENARIOS, PROJECTIONS AND LEGISLATION FOR MARITIME SUPPLY CHAINS.

4.1. INTRODUCTION

This chapter identifies climate change risk scenario projections and implications for Pacific and global MSCs. This forms part of an integrated research methodology in chapter 3 to answer KRQA, whilst addressing key stakeholder uncertainty. It provides contextual information to support analysis in chapters 5 and 6. These scenarios aim to identify projected risks including probability of occurrence, type, frequency, location and intensity. The chapter offers screening criteria to test other projection's reliability and associated implications for MSCs, which is unique to this thesis. Risks also affect the projected frequency, intensity and duration of impact costs. They influence the extent to which stakeholders need to prioritise adaptation (KRQC). This chapter presents downscaled global (section 4.3), Pacific regional (section 4.4) and selected individual island, climate change scenarios (section 4.5). It provides scenarios for B1 (low emissions growth), A1B ('Business as Usual') and A2 (high emissions) scenarios (International Climate Change Adaptation Initiative (ICCAI (2011); World Bank (2012); Australian Government Bureau of Meteorology (AGBM) and CSIRO (2014); WMO (2015a). It provides an overview of existing current legislation, declarations and resolutions, relevant to climate change adaptation within a Pacific MSC context.

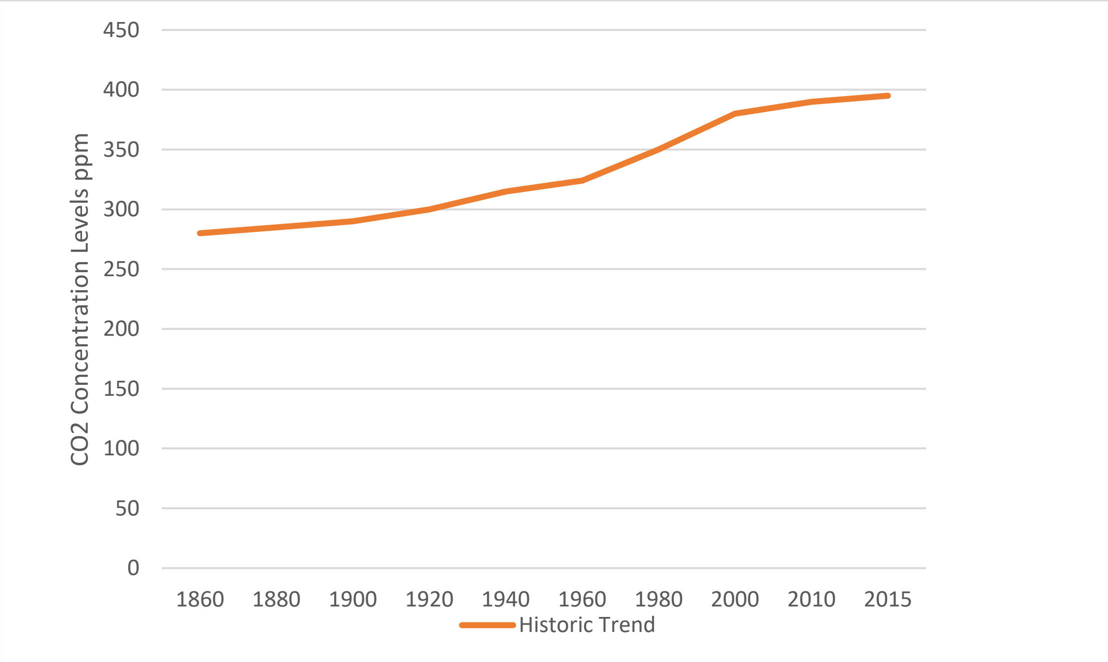
4.2. CLIMATE CHANGE SCENARIO PROJECTIONS AND ASSUMPTIONS

This thesis's theoretical framework addresses incomplete information and imperfect stochastic forecasting capabilities towards assessing exact climate change impacts on Pacific MSCs. Research from Pernetta and Hughes (1992) to Goodrich *et al.* (2015), has focussed on modelling projected risks (KRQA) and associated impact costs (KRQB) with underlying assumptions. To answer KRQC, these sources aim to provide stakeholders with specific guidance over which adaptation actions to prioritise, during pre and post-disruption events. These sources target where to allocate resources effectively and determine the quantity and quality of resources necessary to recover. It is considered sufficient empirical scientific evidence exists from sources including the United Nations (2010), IAPH (2013), Pacific Island Forum (2013), SPC (2014), SPREP (2014), IPCC (2015) and the Australian Academy of Science (2015); to presume climate change actually exists. These are accepted to present direct, short and long term, disruption risks towards the future survival of MSCs. These particularly apply in the Pacific region, studied in detail in the subsequent chapters. Furthermore, the following scenarios are assumed to be true:

I: Global CO_2 atmospheric concentration has increased from 280 parts per million (ppm) in 1850 to over 390 ppm by 2013. This is based on the IPCC's established scientific consensus and Figure 4.1. Figure 4.1 indicates historic emissions growth over time, despite global pledges to prioritise climate change mitigation. (outlined in section 3.5). From 1900-2000 average global surface temperature increased by 1ºC.

II: CO_2 and other greenhouse gases directly affect global climate change through the process described in section 2.2.

Figure 4.1: Historic CO_2 Emissions Scenario Growth



Source: Author.

These produce the following gradual, climate change risk events and impact consequences (KRQA/KRQB). Sections 4.2-4.4 provide more specific projection detail.

- An increase in global average land surface, atmosphere and sea temperature levels, of 1.5-2ºC for the B1 scenario. This occurs even if emissions were to cease, based on historic inventory levels.
- 2.5-4ºC increase for the IPCC (2015) A1B scenario, if emissions are stabilised at the current, medium growth rate by 2100.
- 4-7ºC increases for the IPCC (2015) A2 scenario if emissions are not reduced.

- A 0.5 metre global, average SLR is projected for a low risk, current growth, scenario where emissions are highly reduced, 0.8m rise. This presents a medium risk if emissions are stabilised. Up to 1.1m high is expected for a high risk, continued emissions increase scenario by 2100, in pursuing current, global GDP growth rates of 3-5% annually.
- Other global, Pacific regional and individual increases in sea level, temperature, humidity, precipitation and wind speed are anticipated. Potential variations in wind direction, current, ocean swell, wave energy and sedimentation, are expected as long-term risks.
- Greenhouse CO_2 emissions would have to stabilise around 450 parts per million (ppm) (430–480) at present; no higher than 550ppm (530–580) by 2100, to ensure survival.
- A projected increase in the frequency, duration and intensity of climate- related, natural disaster risks (Figure 1.4).

4.2.1. Stakeholder Advantages of Utilising These Climate Change Scenarios and Assumptions

Challenges faced by many global, MSC stakeholders, in ascertaining climate change risks, impact costs and appropriate adaptation solutions (Beerman 2010, Becker *et al.* 2011; Inoue 2012). These include uncertainty in risk, impact costs and consequences, magnitude, duration, frequency, timing, regional and local patterns. They include separating climate variability versus more prolonged climate change (Hay *et al.* 2003; Krey *et al.* 2014; Victor *et al.* 2014; SPREP and UNDP 2015). This thesis aims to improve upon previous research studies, to identify risks prior to a risk-vulnerability assessment of Pacific MSCs. Improved climate change projections and forecasting methods can also more accurately determine the physical vulnerability and risk exposure of MSC assets and commodities, from related impacts. It aims to integrate baseline historical climate data with future scenarios. This utilises high climate model resolution; through providing additional global, regional and individual scenarios and assumptions, adjusting for these factors. These scenario's objectives are to consider how these risks (identified by this chapter for KRQA) may specifically affect each selected Pacific MSC stakeholder and stage through specific modelled impact costs (KRQB). They determine the particular effectiveness of certain adaptation solutions to address potential impact costs and opportunities associated with these risks (KRQC). Savonis and Potter (2012) consider the purpose of risk projections is to identify and interpret relevant information for stakeholder requirements. These projections incorporate a potential outcome's uncertainty, risk and vulnerability; focusing on combining several tropical climate risks for supply chains. These may assist in enhancing the business viability and survival of entire islands and supply chain. It aims to minimise externality, opportunity, congestion, disruption and delay costs. The above assumptions and scenarios (sections 4.4-4.6) possess the following research advantages:

- *Accuracy:* Climate change scenarios, assumptions and underlying historic baseline data, selection criteria are updated from 2007 IPCC scenario, assumption estimates to the most recent 2015 (IPCC) estimates. Improvements in technology, event observation and forecasting capacity improve projection validity.
- *Reputable/Credible:* The following scenarios utilise the majority of internationally recognised, scientific sources to affirm scenario assumptions and predictions for greater reliability. These provide greater certainty and empirical evidence than dependent stakeholders; who underestimate climate change's potential disruption risk.
- *Consistent:* These scenarios retain consistency across many research sources: World Bank (2012), SPREP (2013), SPC (2014), AGBM and CSIRO (2014), Netherlands Environmental Agency (2014), IPCC (2015). These are used by Pacific state stakeholders in adaptation. Relying on the IPCC report ensures a standardised methodology. It avoids data fragmentation and variable differences across a range of projected causes, impact costs and disruption risks.
- *Comprehensive:* These scenarios and assumptions consider both climate and non-climatic, interdependent causes or drivers of climate change, inter-decadal and inter-annual variability. This technique includes multiple, related risk variables over 100 years to reduce the level and nature of uncertainty of reliable data quality.
- *Autonomously Verifiable/Reduce Complacency:* Certain studies are based on scenario assumptions but do not independently verify them for consistency/accuracy. This further increases supply chain stakeholder uncertainty wishing to swiftly adapt but also to avoid wasting scarce fiscal, time and other resources. Sources including World Bank (2013) and Wong (2015) further multiply systematic error, uncertainty and maladaptation costs. They increase the significant opportunity costs associated with risk underestimation, through failing to justify scenario evaluation/selection criteria and underlying theoretical frameworks.
- *Accessible:* The greater institutional research, information gathering/analytic, technological and skilled professional capacity of developed countries in climate change projections can aid less developed countries including Pacific nations, with similar constraints through accessible data. Pacific nations can reciprocate through providing field research experience of sudden, disruption risks to MSCs. This allows countries to benefit without wasting scarce resources in isolated efforts and implement adaptation strategies more swiftly, to minimise impact costs.
- *Relevant:* To the study's significance or stated RQA-RQC.
- *Simple/Transparent*: minimising litigation, miscommunication, translation and adaptation costs.

- *Effective:* These data sources provide the basis of myriad existing efforts in adaptation for stakeholders. They are advocated in a significant number of existing research sources.
- *Equity:* Data/scenarios are openly accessible to all and simple to verify.
- *Robust/Costs:* It provides autonomously verified, consistent climate change projections, that are international government accepted (IPCC 2015), downscaled to Pacific regional and individual island examples. This minimises individual stakeholder research, training, business forecasting, administration and adaptation costs. Data needs to be succinct, accessible, and affordable.
- *Flexibility:* The three emission scenario types forecast over short (2030), medium (2055) and long term, (2090-2100), include global, regional and individual Pacific nations.
- *Data Availability:* Newly present high spatial-temporal resolution models combined with satellite imagery for individual islands improves downscaling from general circulation models to regional scale models. It improves data quality.
- *Satisfying Stakeholder Requirements* (Section 2.2).
- *Practical:* It matches computational, institutional and informational capacity; given Pacific supply chain, organisations and governments' resource constraints.
- *Comparable/Generalisability:* Utilised by myriad stakeholders, these assumptions, scenarios and method techniques can be applied to different case studies with a common standard of evaluation.

As an extension to previous impact studies of Oxfam Australia (2009) and Marra (2014), a significant adaptation constraint includes insufficient or inconsistent information. Therefore, models and methods require even more research before any action can be undertaken. Previous studies have indicated this as a recurrent stakeholder concern e.g. Sikivou, Pelesitkoti and Lal (2009); Lawrence and Manning (2012) and Whetton *et al.* (2012). These argue scientific climate change projections, underlying data and research serve no purpose if they conflict between different authorities and is overly technically complex. In contrast, this thesis advocates the IPCC 2015 report contains the globally most reliable, consistent, accessible and cost-effective approach to forecasting climate change. It presents the most robust estimates. It is accepted by a majority of nations with internationally reputable and accurate scientific resources. This thesis aims to simplify technical, IPCC projections. This ensures they can be applied through modelling specific risks considering implications of projected impact consequence. These risks are applied to a local/regional scale from a global scale (USP 2013a). Each projection and underlying assumption have been ascertained for consistency and reliability with leading established scientific institutions, individuals, research sources, meteorological agencies and Pacific observations. These are accepted and utilised by UNFCCC (2009), SPREP (2012), Pacific Island Forum Secretariat (PIFS)

(2012a), USP (2013), SPC (2014) and AOSIS (2015). These are the most frequently cited and significantly active organisations concentrating on Pacific climate change.

Although IPCC estimates may still retain uncertainty over future specific emissions and climate change risk event probabilities, global climate change estimates range from 90-99% probability of occurrence. This is based on historical data, a related average increase in disasters and the submerging of significant Pacific land areas, major polar ice melting and other effects identified here. Koetse and Rietveld (2010) note most climate models predict similar trends. They agree on the problem despite the uncertainty of specific impact costs. This thesis represents an improvement over previous sources e.g. Hahn (2011), Hay (2011) and Savonis, Burkett and Potter (2012) providing adaptation solutions and methods. Their assumptions and scenarios are implicit rather than critically examined. This section proposes the above research advantages are combined as assessment criteria for any MSC stakeholder seeking to independently determine the reliability of projected assessment impacts. Stakeholders can consider the best performing models with the most probable projections. These criteria can assist not just Pacific MSC stakeholders but also affected global stakeholders to reduce issues of asymmetrical information, time, financial and other concerns. Understanding how climate change will personally affect each stakeholder; enables them to prioritise adaptation. It minimises disruption risks and impact costs.

Generally, sources actively propose affected stakeholder consultation, e.g. Australian Government Department of Environment and Heritage Australian Greenhouse Office (2009) and SPC (2015). However, findings' validity can be compromised without these MSC stakeholders being able to identify specific climate change data and scenario assumptions; as well as impact costs, risks and consequences directly affecting them. These stakeholders can be wary of maladaptation costs from asymmetrical information over issues of timing, intensity and actual consequences and perceptions of scientific uncertainty. Many are often risk averse in responding to this threat. Through providing specific scenarios and assumptions with outlined research advantages, this thesis aims to reduce uncertainty factors prompting moral hazard and inertia by stakeholders. It utilises the online tool, Pacific Climate Futures; allowing a range of scenarios and assumptions. It provides the above research advantages. The aim is to exploit high resolution, transparent, baseline climate data for stakeholders, sourced from local countries. This aids in identifying pre-, actual and post-event trends to prepare in minimising vulnerability. It optimises resource allocation, where data observations are repeatable and consistent. It assists Pacific nations/organisations (Figure 4.14), in preparing national adaptation policies, given existing familiarity and data availability by stakeholders.

The tool allows users to project individual, variable risks for various IPCC scenarios. It utilises global, regional and nation specific, circulation models and assumptions, determined by IPCC 2015, AGBM and CSIRO (2014) and each Pacific nation's meteorological services. The user can specify time horizons in a simplified graphical representation. The user can downscale to localised impacts if necessary. The tool's quality assurance is based on an established scientific consensus. The majority of global nations, their populations and international organisations recognise this, ratifying the 2016 Paris Agreement and the 1999, UNFCC. Evidence is contained in the 2015 IPCC, Final Report. Unlike the summarised, econometric models in chapter 3; Whetton *et al.* (2012) proposes flexibility advantages of users selecting variables to identify the most relevant, efficient, plausible scenarios and assumptions. Each scenario and assumption have been independently verified; based on estimates consistent with these nations, IAPH (2013), (WMO) (2014) and IPCC (2015) report. It is confirmed via historic data observations from each Pacific island's meteorological service. These aim to provide reliable, relevant, scenarios that are consistent, simple and comparatively accurate, to aid anticipation and adaptation. This is consistently recommended by literature including Veitayaki, Manoa and Resture (2007), Marra (2014); Field *et al.* (2014).

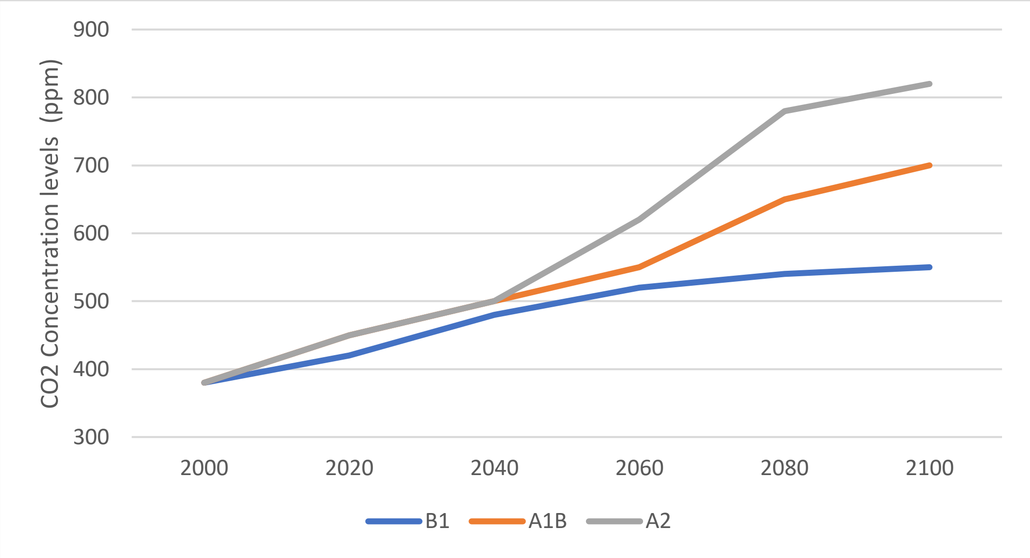
4.3. GLOBAL CLIMATE CHANGE SCENARIO PROJECTIONS AND IMPLICATIONS FOR SUPPLY CHAIN STAKEHOLDERS

The IPCC (2015), AGBM (2014) and other Pacific meteorology services conventionally utilise baseline historic data. This provides a mechanism to help determine future, climate change scenarios. This section outlines three scenarios (B1, A1B and A2) that will be utilised to identify potential future risks for Pacific MSCs on a global scale (KRQA), over 3 time horizons. B1 is used by the IPCC (2015) and international, climate change policy makers (SPREP and UNDP 2015) to refer to a low emissions, growth scenario. This occurs if humanity were to become substantially more environmentally sustainable; to convert from an industrial to a services-based economy which is less resource and emissions intensive and restrict population growth to reduce emissions. A1B refers to a medium, emissions growth scenario or "business as usual" if population and economic activity were to continue at current growth levels. A2 refers to a projected, high emissions growth scenario. This occurs if developing countries do not stabilise population, dramatically reduce emissions and pursue the globalisation or industrialisation, economic activity levels of developed nations. The three projected time horizons (2030, 2055 and 2090) are defined as short, medium and long-term periods for MSC stakeholders to adapt.

4.3.1. Projected CO_2 Emissions Growth

Global projected, CO_2 emissions are projected to increase from an actual baseline of 380 parts per million (ppm) in 2000 to 550ppm under a B1, 700ppm for an A1B and over 800ppm for an A2 high emissions scenario. This is based on IPCC (2015) data estimates and illustrated in Figure 4.2. The implications of increased emissions possess significant, disruption risks and direct and indirect impacts with adaptation costs for MSC's. Increased ocean acidification and changes in salinity/pH balance from emissions; project further disruption costs to natural resources and coastal protection roles of coral reefs and other tropical ecosystems. These projections illustrate how vital it is for MSC stakeholders globally from producer to governments, ports and intermodal transport to consumers; to prioritise not just mitigation but adaptation.

Figure 4.2: Global Projected CO_2 Emissions Scenario Growth

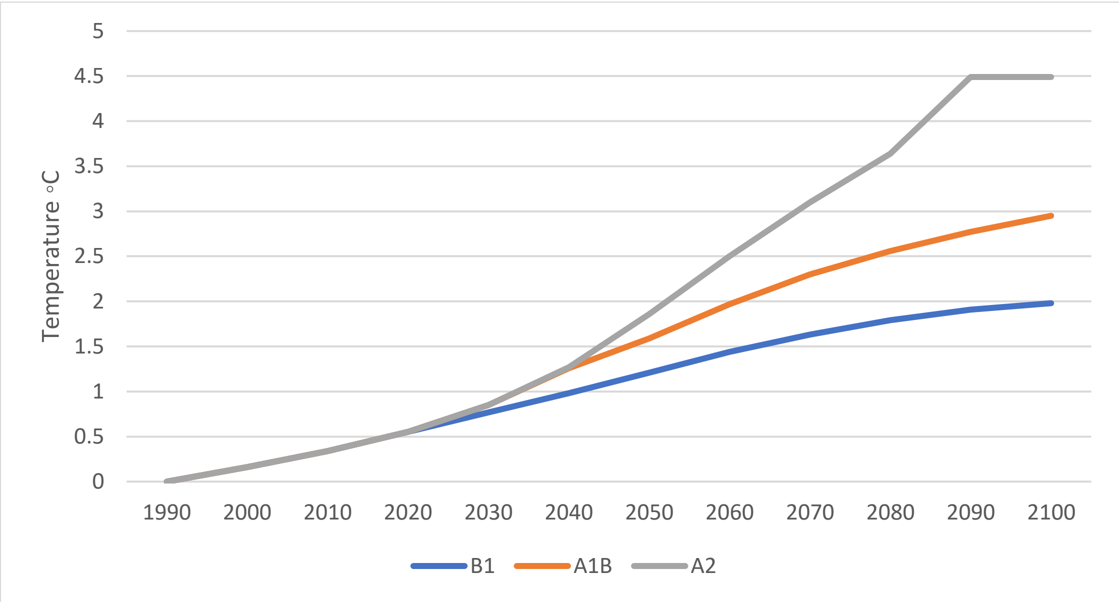


Source: Author

4.3.2. Historic and Projected, Global Mean Temperature Rise

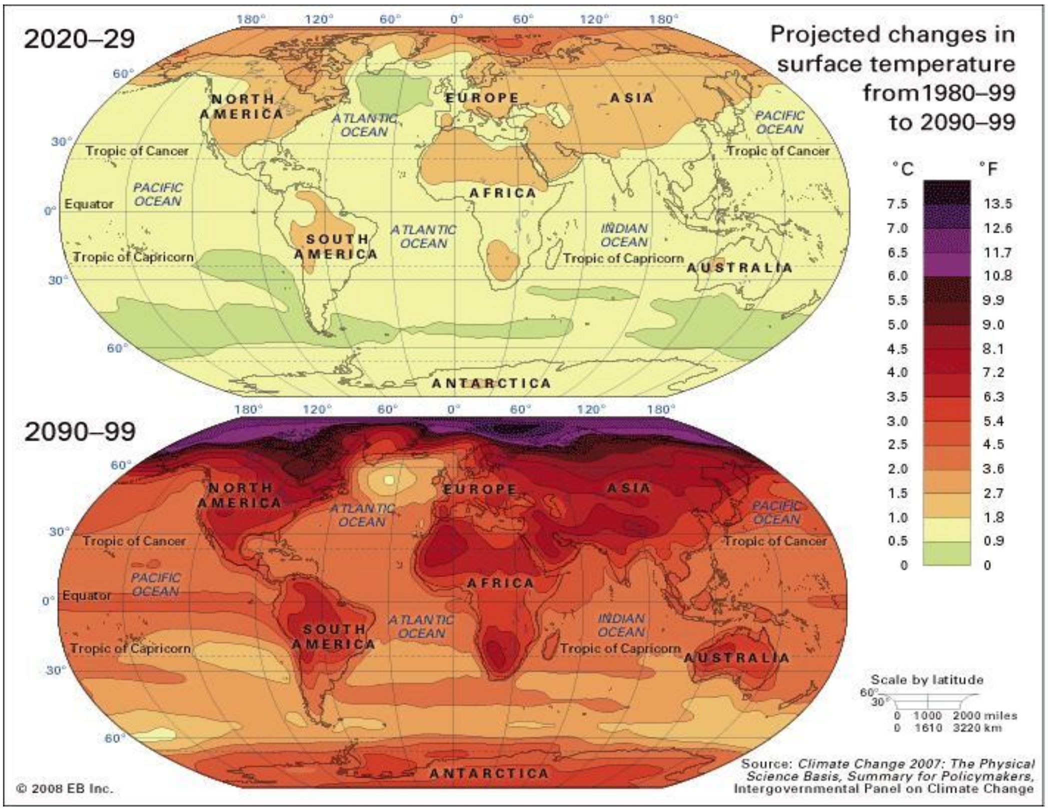
Based on IPCC (2015) data estimates and Figure 4.3, global, mean surface temperature rises are projected to increase from an actual baseline of 0ºC in 2000 to 0.85ºC by 2030 under all 3 scenarios. By 2055, emissions are projected to diverge, around 1.2ºC under a B1, 1.59ºC for an A1B and 1.86ºC for an A2 scenario. This increases to an average of 2, 3 and 4.5ºC respectively by a 2100, long term projection. Figure 4.4 (Encyclopaedia Britannica 2008) provides an alternative visual representation of how specific world regions will be affected and vulnerable under an A2 scenario. Increased global mean temperature implications for MSCs are indicated throughout this thesis possessing significant disruption risks, direct and indirect impact and adaptation costs. These projections illustrate how vital it is for these stakeholders globally to adapt, enhancing vessel and infrastructure resilience to higher temperatures and increased salinity. Higher temperatures contribute towards an increased frequency of droughts, greater temperature extremes; reduced water; higher evaporation and evapotranspiration rates. This affects future climates, natural resources and productivity, (Simpson *et al*. 2010; Collins *et al.* 2010; Matear 2014). According to these sources climate change projections may include slower ocean currents/thermohaline circulation, complicating navigation.

Figure 4.3: Global Mean Surface Temperature Change



Source: Author.

Figure 4.4: Projected Climate Change, Surface Temperature Changes 1999-2090

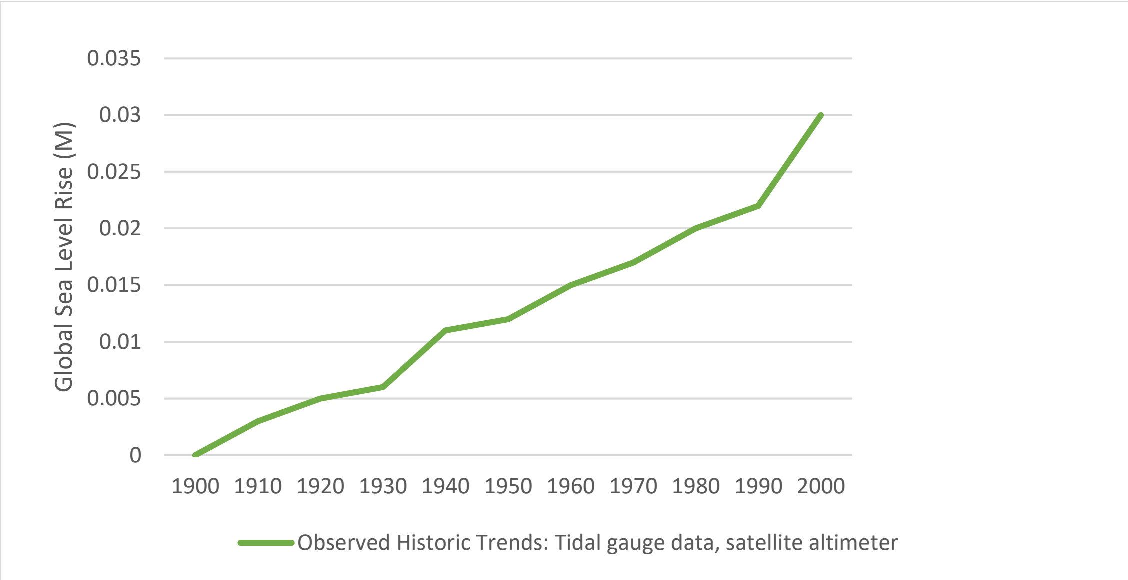


Source: Encyclopaedia Britannica 2008, page 72.

4.3.3. Historic and Projected Sea Level Rise

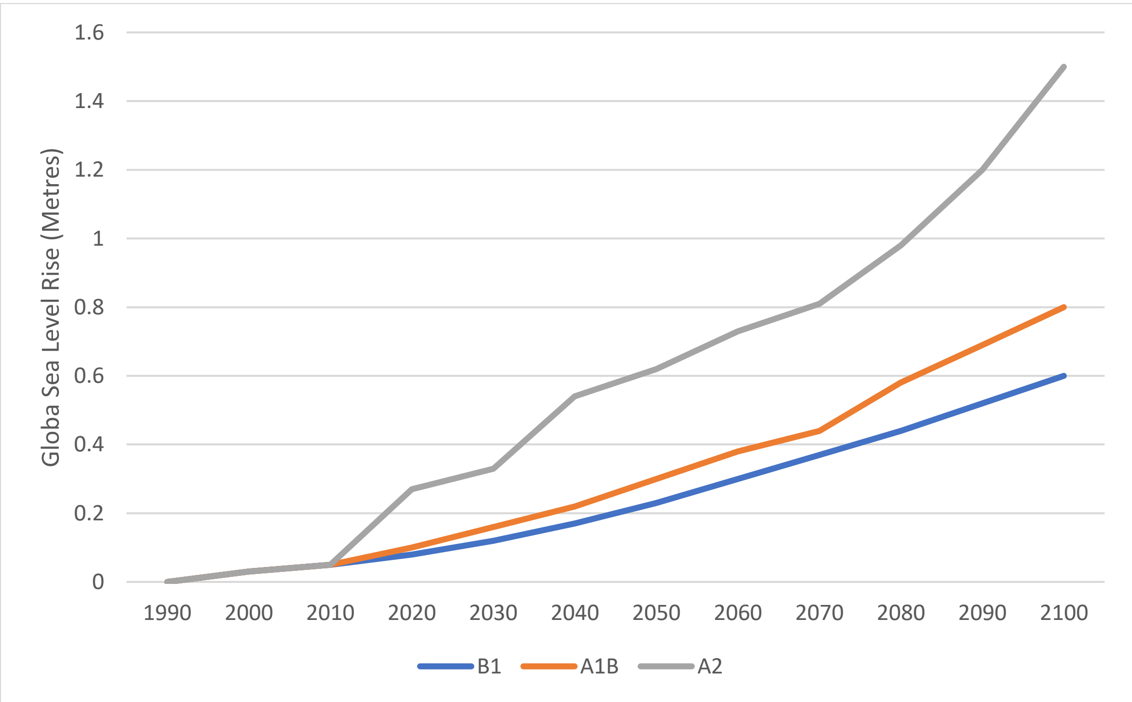
IPCC (2015) data from tidal gauge data and satellite altimeters; illustrated in Figure 4.3, estimate global average, SLR rose historically from a 0m baseline in 1900 to 0.03m by 2000. The rate of increase has substantially accelerated from several, global, climate change related factors. These include accelerated polar melting of sheets, glaciers and ice caps, land-based water discharges and thermal ocean expansion from increased mean temperatures. These have expanded from an average of 1-1.5mm (1900-1980) to 3-3.5 mm per year (1980-2014) (AGBM 2015). It's projected to reach 8-10 mm per year by 2100, if global climate change trends are not stabilised. From IPCC (2015) data and Figure 4.6, global, mean SLR is projected to increase from a 0 baseline in 2000 under all 3 scenarios. However, by 2030, scenarios are projected to diverge around 0.12 metres under a B1, 0.16m for an A1B and 0.33m for an A2 scenario. This increases to an average of 0.23, 0.3 and 0.62m respectively for a 2055, medium time horizon. By 2100, MSC stakeholders are anticipated to experience a mean, SLR of 0.6 (B1), 0.8 (A1B) and 1.5m.

Figure 4.5: Historic Average Global SLR 1900-2000.



Source: Author

Figure 4.6: Global SLR, Climate Change Risk Projections



Source: Author.

4.3.4. Implications of Global Climate Change for MSC Stakeholders

The implications of increased global SLR, temperatures and other long-term risks for MSC stakeholders are indicated throughout this thesis. Specific Pacific nations and their physical, economic and environmental survival prospects; are threatened under all three projected scenarios. Stakeholders may have to adapt to a world where low altitude countries, ports, populations, infrastructure, resources and coastlines experience substantial disruption risks. Thorpe and Fennel (2012) from reviewing several hundred sources, conclude sufficient consensus exists about the actual effects and process of climate change. This justifies stakeholders adapting from the Precautionary Principle; even where various climate change models provide a range of confidence intervals, risks, impact costs and solutions, not the actual occurrence. This thesis includes projections to identify risks (KRQA) assist adaptation strategies (KRQC) and in response to the following stakeholder concerns expressed as existing literature weaknesses or possible directions for future research.

To assist stakeholders in identifying potential risks; Savonis, Burkett and Potter (2012) argue for transparent data. This allows for the uncertainty of gradual and sudden risks and increased information on the likelihood and extent of extreme related, disaster events as possible risks. Kinrade and Justus (2006) argue for higher resolution of existing data models to enhance accuracy. They argue most global circulation models are flawed in failing to consider projected local and sub-regional, climate change impacts. Inoue (2012) considers a lack of projection studies exists globally, which concentrate on localised coastal areas, ports and supply chains when reviewing existing IAPH, climate change preparations; Becker *et al* (2011), Koshy (2008), Kramer *et al.* (2013) and ADB (2013) further indicate the dearth of localised projections and models in existing studies on climate change and supply chains. Few consider localised, interdependent environment-ocean-land-atmosphere as climate change factors, to ascertain an inventory of exposed coastal assets/supply chain vulnerabilities. This review suggests stakeholders would benefit from more representative studies utilising projections for specific regions, islands and MSC case studies. This identifies and minimises potential risks, impact costs and adaptation solutions more accurately.

Beerman (2010), CSR Asia (2011) and BSR (2014) note an emergent supply chain stakeholder requirement for more practical and specific/localised projections. This assists to identify specific risks, impact costs and opportunities for individual stages including businesses (SPREP and CSIRO 2011). A lack of studies specifically focussing on private sector climate change adaptation, rather than for governments and local communities, is further criticised by Aggarwal *et al.* (2011). This reviews private sector adaptation for OECD countries' supply chains. From reviewing PCARFI (2013), accurate projections might incentivise private sector funding for enhanced supply chain resilience and other adaptation solutions. Externally financed, situational awareness and accurate information especially aids Pacific nations with limited government funding. Simpson *et al.* (2013) in considering specific SLR at local level; points moral hazard as a reluctance to invest in supply chain adaptation without more certain information. Accurate detailed projections can further aid impact damage cost estimates and various Pacific Ocean/island ecosystem replacement values (Wilby and Dessai 2010). This improves impact cost analysis for supply chains (KRQB). Further benefits of using local level Pacific data and examples exist e.g. a comprehensive AGBM and CSIRO (2014) review. Previous natural disasters and gradual risks can demonstrate current vulnerabilities and disruption risks to minimise opportunity, delay, externality and maladaptation costs for anticipated events.

It is an emerging legal requirement for key infrastructure and systems of more countries, such as ports and MSCs, to consider projected climate change and to disclose emissions and risks (Maunsell 2008; UNEP 2008; PIFS 2012). It also aims to aid companies especially those listed on the Australian, US, UK and other stock exchanges, (whose supply chains may stretch as far as the Pacific.) These must identify and disclose physical risks/impact of climate change for individual businesses. Awareness may reduce legal, reputational, litigation and other noncompliance risks, including stakeholder pressures. This thesis aims to minimise legal, compliance costs for its selected Pacific MSC example. It provides specific global, regional and local projections to determine relationships between key risk variables and MSC stages. However, a significant constraint to implementing adaptation solutions, is most supply chain, business planning horizons are short term: 1, 5 or even 10 years, yet current reviews envision 100 years for projected climate change (Garnaut 2008; AGBM and CSIRO 2014; IPCC 2015).

Pacific supply chain stakeholders require a tool such as Pacific Climate Change Futures, or literature proposed models in Chapter 3. Stakeholders need projections considering a range of scenarios and time horizons to aid effective decision making when planning to adapt businesses. This tool approach is flexible enough to aid adaptation solutions (KRQC) identified in Chapter 2. Examples include revising technical design standards, climateproofing existing infrastructure, equipment, transport and processes to determine the degree of resilience. It includes the stress and asset lifespan to determine adaptation and post-event, recovery and replacement cost; disaster reduction and risk management responses (Alesch *et al.* 2001; Fletcher *et al.* 2013; Babister and Ball 2014). This is necessary as risk may be significantly underestimated by stakeholders relying on guidelines e.g. Beca International Consultants (2010) for Kiribati and Ports Australia (2014). Its National Ports strategy considers standards of 50-100yrs in design but significantly underestimates risk using a probability of 1:100 years of significant storms.

Other ports generally prepare 20-30 years in advance (Ports Australia and Freight Logistics Council of Western Australia 2014). Therefore, this thesis considers accurate projections contain advantages for MSC stakeholders to assess how risks originate and subsequently develop. It determines how impacts can differ across various economic sectors, stages, stakeholders, countries and even between short, medium and long-term time horizons (KRQB).

Although data estimates exist for other risk variables, technical sources have principally concentrated on graphical representations of historic and projected global emissions, mean surface temperature and SLR. Examples include International Centre for Trade and Development (2010); Collins (2010), Nichols *et al.* (2011) and Woolhouse and Lumbroso (2015). In projecting global scenarios, this thesis includes implications for MSCs. It notes a lack of past studies focusing specifically on developing countries and tropical climate variations for projections. This chapter and its projections aim to contribute towards stakeholder awareness of risks. This must mainstream climate change information including data availability, the cost effectiveness of proposed responses and the urgency of risks for MSCs through projections, updating existing Pacific studies. Scenarios can further aid risk identification, assessment severity and prioritisation. They ascertain direct and indirect impact costs, timing and type of adaptation response (Stewart and Deng 2013; Johnson, Burton and Jones 2013; Netherlands Environmental Assessment Agency 2014). Comparatively accurate climate projections and short-term, meteorological data are essential to ensure business continuity, future profits and rates of return on investment for stakeholders.

Identifying possible global, regional and local climate change impacts upon MSCs for the Pacific further emphasises the need to incorporate scenarios and assumptions into any subsequent methodology. This computes more accurate integrated risk-vulnerability and impact cost analyses outlined in Chapters 3 and 5. These projections further indicate the urgency of stakeholders to react to climate change, to minimise these threats as the ultimate risk threatening the future economic, environmental and physical survival of Pacific MSCs. Kinrade and Justus (2006) state research needs new tools for diagnosing the probability of climate change to aid effective risk management. High resolution impact data has already aided Caribbean, coastal supply chains that are similarly climate risk exposed (Lorde *et al.* 2013). For example, stakeholders could use Google maps and satellite imagery to identify impacts of SLR, temperature and other risks. This thesis provides specific projections and a theoretical screening framework for these stakeholders to access to data and scenario simulations independently. This reduces the need to rely on research of external consultants and conflicting research studies. Accurate, localised, updated projections enable stakeholders to evaluate each adaptation strategy's costs and benefits and individual solutions (KRQC) to minimise impact costs.

This chapter also focuses on MSC concerns in providing projections and screening criteria for those stakeholders citing constraints of resources, time, research expertise, staff, information access and technical barriers. This establishes constraints to adaptation; answering ARQI. These are identified as key challenges for small island, developing states, especially in the Pacific region by Forbes and Solomon (1997), Magnan (2014) and Kim *et al.* (2015). Another significant constraint is the limited availability of shared information and cooperation across different stakeholders; even when mutually advantageous in lowering costs. Accurate information also assists in identifying an event's timing, threats and opportunities presented. These further indicate the need for a joint risk, cooperation approach in information, communication and adaptation across entire Pacific MSCs, integrating stakeholders. This aims to minimise disruption costs to international trade and economic activity, throughout an event.

4.4: PROJECTED PACIFIC REGION, CLIMATE CHANGE SCENARIOS

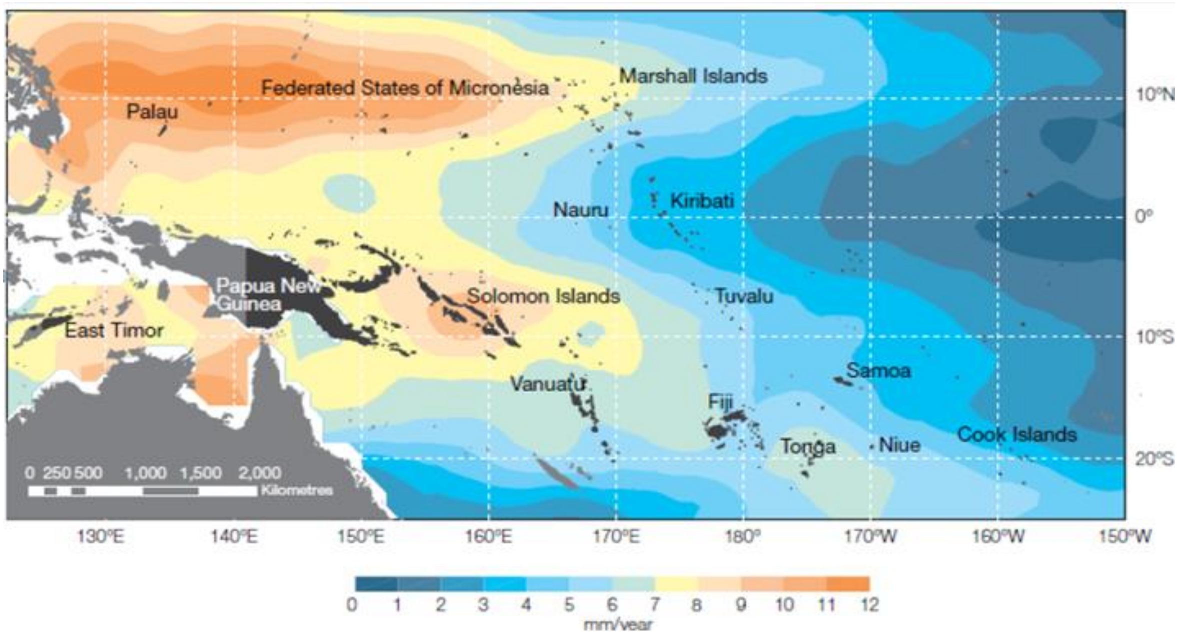
Previous studies have provided global climate change projections; including AGBM and CSIRO (2014), SPREP (2014) and IPCC (2015). An increasing number, (Moser, Williams and Boesch 2012; Whetton *et al.* 2012; Brown *et al.* 2013), have realised the inadequacy of global, general circulation models. These models' baseline data and satellite observations range in cells 70-200 km^2 wide. This complicates identifying specific risks and associated impact costs for MSC stakeholders seeking information at Pacific regional and individual island scale. This section projects downscaling potential effects. It uses the Pacific Climate Change Futures tool devised in 2014 to model scenarios for individual, nations and interdependent stakeholders. To satisfy the screening criteria summarised in 4.2 it uses projections and field observations of the main Pacific, political, economic, academic, environmental and community organisations. These include SPC, USP, SPREP, AOSIS, SOPAC, individual governments, UNDP, Pacific Climate Change Adaptation Initiatives and World Bank. Downscaling becomes more practical with improved data quality and accuracy over a longer time period. This tool identifies Pacific Ocean and climate hazards potentially affected by climate change. It indicates further MSC implications (section 4.4.1), to reduce stakeholder uncertainty, moral hazard, risk aversion, asymmetrical information and maladaptation costs (KRQC).

Based on the sources cited above and thesis references; Pacific regional climate change is anticipated to include similar rates of land and sea surface temperature rise as global climate change projections for all three scenarios. This rate is slightly lower than the global average, based on higher thermal ocean expansion absorption, as small islands. Although exact magnitudes will vary across islands, the Pacific region outside Australia and New Zealand possesses certain regional similarities in projected climate change for ocean surface temperature as for land. Overall, projected temperature changes are anticipated to be lower than for continental landmasses with fewer water surfaces to absorb temperatures (Meyssignac and Cazenave 2012). Pacific regional climate change is projected to include an increase in heatwaves. The recurrence intervals of temperature maximum days are expected to increase. PACCAP (2014) observed since 1951, the number of temperature days exceeding 35ºC has increased from an average of 20 to 45-80 across the Pacific. This increases the probability and associated supply chain, disruption costs of heatwaves and lower productivity.

However, regional climate change, circulation models differ from global projections primarily in emphasising particular physical vulnerability across the Pacific. Precipitation and other variables change over regions and specific Pacific islands, based on local geophysical, climate, environment and human conditions, scale, timing and format. This is partially emphasised through Figure 4.7. Projected Pacific SLR is likely to exceed the current global average rate of 3.2 mm per year, from 3-5mm per year in the Cook Islands. It is projected to increase for an average 4-7 mm for most Pacific nations; up to 9-12 mm per year for the Solomon Islands, Palau and Federated States of Micronesia. Regional SLR is influenced by Pacific Ocean dynamics. Factors include the regional mass distribution of Earth's crust but also currents, localised surface winds, changes in salinity, bottom pressure, and SST, which could alter through climate change (Fletcher and Richmond 2010; Hemer, Katzfey and Hotan 2011; Mayo-Ramsay 2012). From 1900-2000, average Pacific Ocean surface temperatures rose 0.7ºC. The Pacific increased its potential capacity to forecast regional SLR and temperature through aid agencies. It prioritises forecasting through 12 stations of the Australian funded, South Pacific Sea Level and Climate Monitoring Project (AGBM 2015). Higher projected SLR increase the predicted probability of flooding, increased wave energy and sedimentation, eroding existing coastal and engineering protection. These further indicate the need to prioritise adaptation solutions identified in section 2.6, to answer KRQC. This aims to minimise disruption to MSCs' future, wherever practically possible.

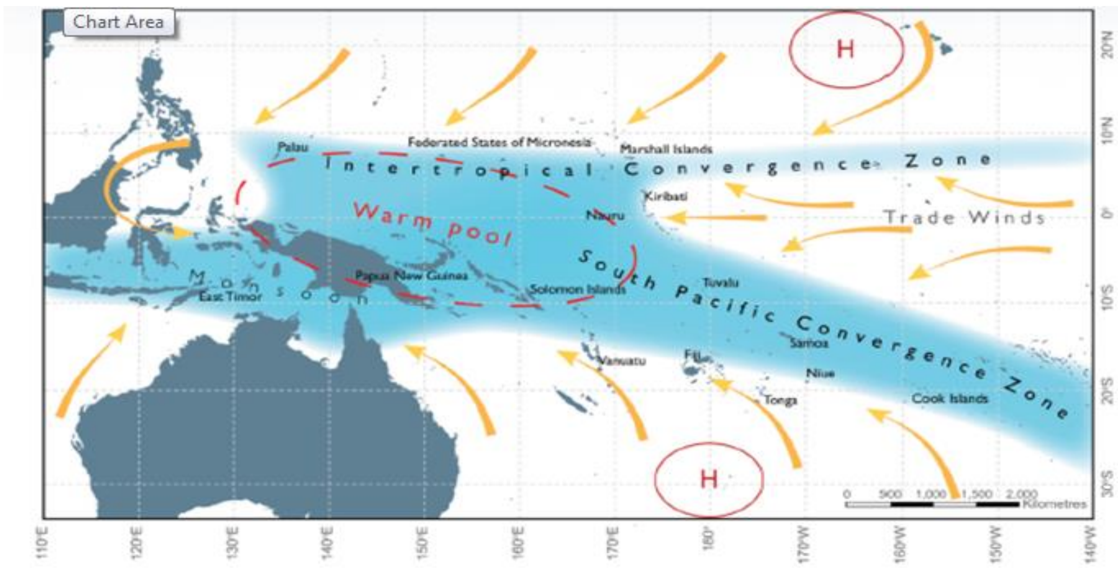
Projected Pacific regional climate change may further affect MSCs and stakeholders through regional influences including the South Pacific, West Pacific Monsoon and Intertropical Convergence Zone (Figure 4.8). Subtropical high-pressure zones are indicated by H. Yellow arrows indicate surface winds. Moser, Williams and Boesch (2012); AGBM (2015) and IPCC (2015) project minimal variations to these influences regulating climate variability. A slight increase in average wet season and reduction in low season precipitation is expected. Using CMIP5 models, these sources indicate a high probability of a reduced risk frequency of tropical zone cyclones north of 20˚ south latitude. However, it predicts an increased frequency, duration and intensity in disruption impact costs below this interval. Possible changes in wind may influence slightly ENSO, Inter-decadal Pacific and Pacific Decadal Oscillations, currents and cyclone formation. However, projection estimates remain inconsistent from observed sources (Collins 2010; Pacific Climate Change Science Programme 2013; Jia *et al.* 2015).

Figure 4.7: Pacific Regional Projected Mean SLR



Source: Australia Government Bureau of Meteorology and CSIRO 2014, page 10.

Figure 4.8: Pacific Regional Climate Change Influences.



Source: AGBM and CSIRO 2014, page 4.

4.4.1. Implications for MSCs

This chapter considers accurate projection implications for Pacific MSCs as part of the answer to KRQA. This provides sufficient information to enable all stakeholders to determine their vulnerability. It understands each risk impact cost and adaptation response is not homogenous. Each stage, nation, stakeholder and commodity may differ in its risks and impact costs. This necessitates statistical and dynamic downscaling from global scenarios with local data sets. It requires a bottom up approach, to identify regional and individual supply chain effects. The advantages of these particular models and scenarios is they consider divergences in the Pacific's regional climate and ocean ecosystem. These models incorporate differences in economy, geophysical conditions and interdependent, climate-related drivers. This represents a departure from the majority of climate change impact studies on supply chains reviewed in Chapter 3. These generalise climate change effects globally, without considering specific consequences may vary across locations. This increases the probability of maladaptation costs and risk underestimation. Developing countries cannot afford this, particularly Pacific Islands with significant time, fiscal, labour and other identified constraints.

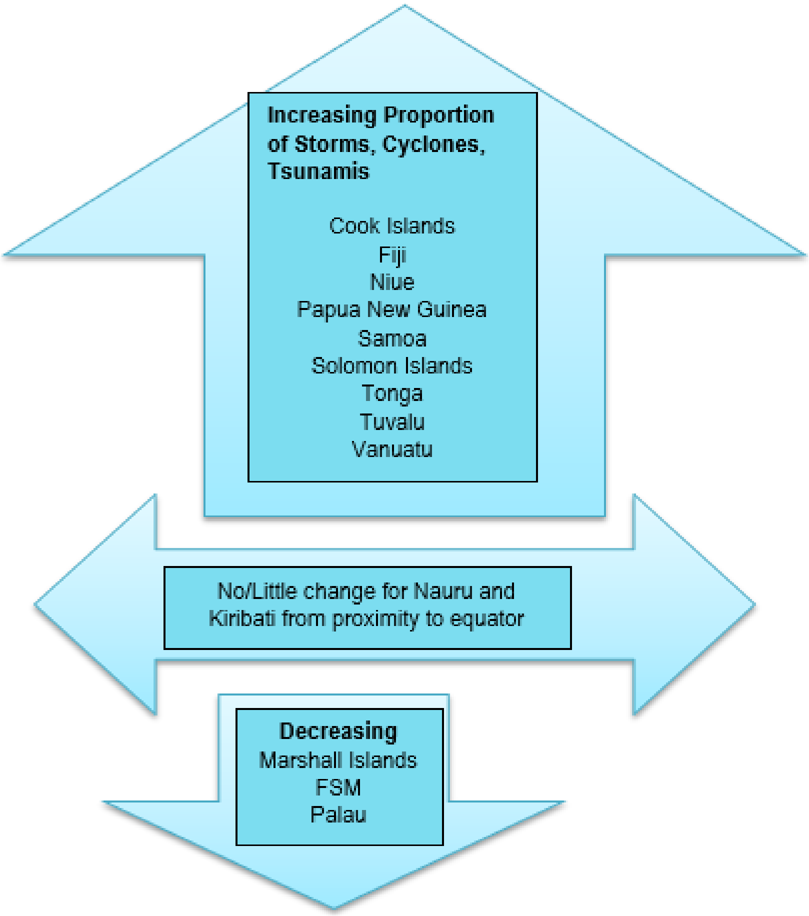
Further Pacific regional implications for MSCs from Figure 4.8, include projected, increased minor seasonal, inter-decadal and other climate change variability. These potentially influence shipping movements and corresponding, future trade patterns of demand with supply (Wells 2013). Annual, mean wave, significant height increases are projected from increases in wind speed throughout the South Pacific Ocean, (Pacific Islands Climate Change Cooperative 2015). These may increase physical risks to vessels and the probability of flooding, creating storm surges to coastal economies, infrastructure and ecosystems. Matear (2014); WMO (2015); SPREP and UNDP (2015) anticipate only minor variations in Pacific regional, wind direction, speed and currents. MSCs may be influenced through altered navigation, trade routes and the distribution or location of maritime resources. Melanesia is anticipated to experience greater rates of ocean acidification from higher temperatures and greater coral reef access; than Micronesia and Polynesia (AGBM 2015). The projected growth in ocean temperatures, regional pH balance and salinity from a 0.1 increase (1900-2000) to 0.3-0.5 by 2100, with increasing ocean acidification, further expands vulnerability. It further threatens the natural coastal protection and maritime resource functions of coral reefs and other maritime ecosystems. It increases the corrosion rates of vessels and coastal infrastructure. This subsequently increases potential maintenance and repair costs for stakeholders.

Specific Pacific regional risks will produce higher, proportional impact costs over a smaller land surface and lower altitude, being more physically exposed than non-Pacific regions. Risks are projected to lower in frequency but increase in duration and intensity. An increase in sudden risks may further multiply port closure and disrupt interconnected economic hinterlands and MSC functions. This will damage exposed coastal infrastructure, assets and ecosystems and further justifies stakeholders prioritise adaptation strategies identified as KRQC. To adapt further, stakeholders should utilise existing data observations to project regional climate change but also focus on individual island projections (as justified in section 4.5).

4.5. INDIVIDUAL PACIFIC ISLAND CASE STUDY, PROJECTED CLIMATE CHANGE SCENARIOS

This thesis was partially motivated by reviewing a significant number of climate change, impact studies that treat the Pacific region as homogenous (ADB 2013; UNCTAD 2014; Goodrich *et al.* 2015). This reduces the effectiveness and relevance to specific MSC stakeholders seeking to evaluate potential consequences and determine appropriate, effective adaptation responses with minimal transaction costs. The Cook Islands case study was selected on site specific criteria (Chapter 3). Providing scenarios emphasises how projections can diverge across different island supply chains, with divergent risks and impact cost consequences. Figure 4.9 illustrates this for projected changes in drought and storm frequency. Localised Pacific island risks are anticipated to affect thermal gradients and atmospheric pressures, by the scientific projections and historic, field data observations of Dronkers *et al.* (1990), Gero *et al.* (2012), AGBM (2014) and IPCC (2015). These influence local winds, currents, subsequent sedimentation rates, coastal erosion rates and vulnerability to shoreline exposure, tidal and wave energy for stakeholders. Localised temperature changes for individual Pacific islands influences coastal upwelling, local pH salinity and rates of ocean acidification. Local sea level changes may affect changes in scour, sediment and degree of dissipated wave energy and ocean swell. Sea surface temperature changes are affected by localised water column vertical stratification as interconnecting links of an ocean–land–atmosphere, model system (Hay 2011; Correro, Schwartz and Wenger 2011; Kunreuther *et al.* 2014).

Figure 4.9: Expected Pacific Island Climate Changes



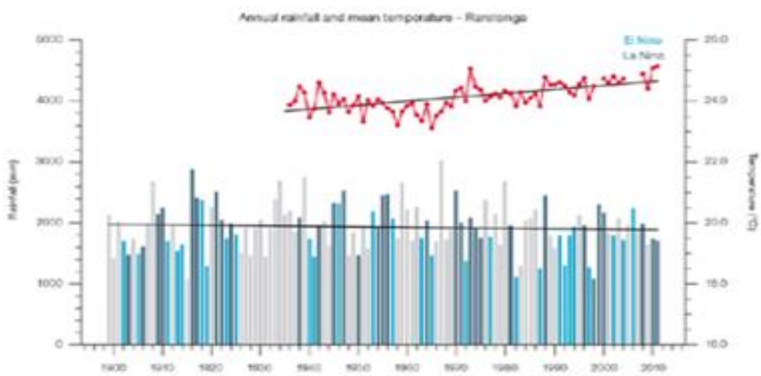
Based on AGBM and CSIRO, 2014.

4.5.1. The Cook Islands

The Cook Islands and other Pacific nations experience a near equatorial, tropical climate with similar characteristics in air/sea surface temperatures, seasonal variations, humidity, winds and other climate related factors (Mori *et al.* 2013; New Zealand Office of Chief Science Advisor 2013; McCubbin, Smit and Pearce 2015). Climate varies from a minimum temperature range of 19-24^{0}C in July (Figure 4.10) to a maximum of 27-30^{o}C in December. Based on local data and Pacific Climate Future, model projections,

Figure 4.11), projected mean temperature is expected to increase from a 0º Celsius baseline in 2000 for all three scenarios to a 0.5º C increase under a B1, 1.1º C (A1B) and 1.5º C (A2) scenarios for the short-term adaptation (2030) time horizon. By 2055 for a medium time horizon; mean projected temperature is expected to increase by 1º C under a B1, 1.5º C (A1B) and 3º C (A2) scenarios. This accelerates to 2º C under a B1, 3º C (A1B) and 5º C (A2) scenarios under a long adaptation time horizon (2090 - 2100).

Figure 4.10: Cook Islands Climate: Mean Annual Precipitation and Temperature

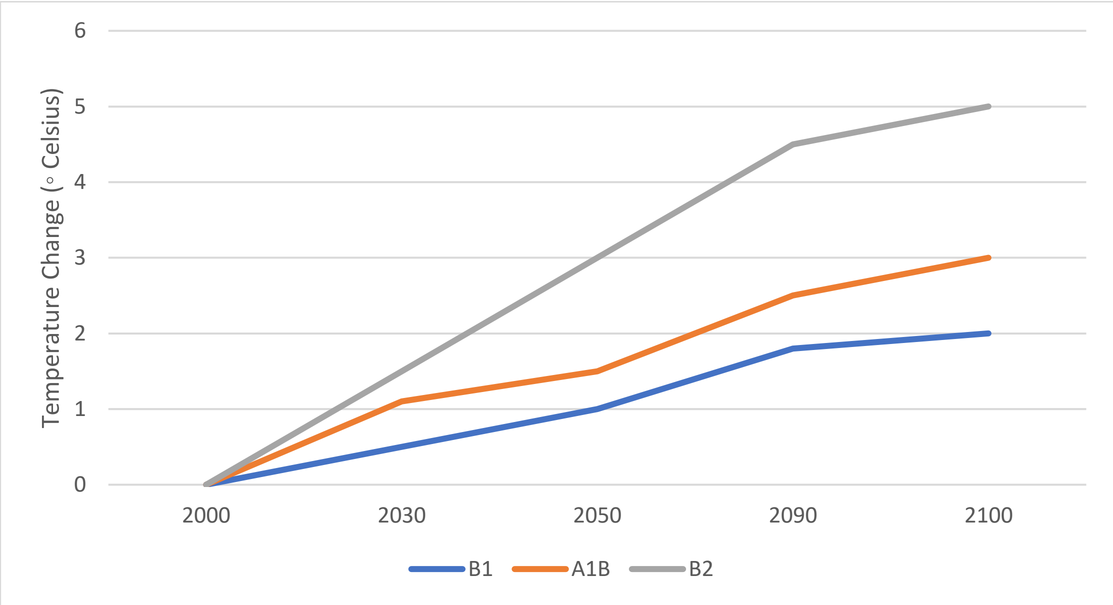


*The red graph and its linear trend line show mean air temperatures. Light blue, dark blue and grey bars denote El Nino, La Nina and neutral years

Source: AGBM and CSIRO 2014, page 32.

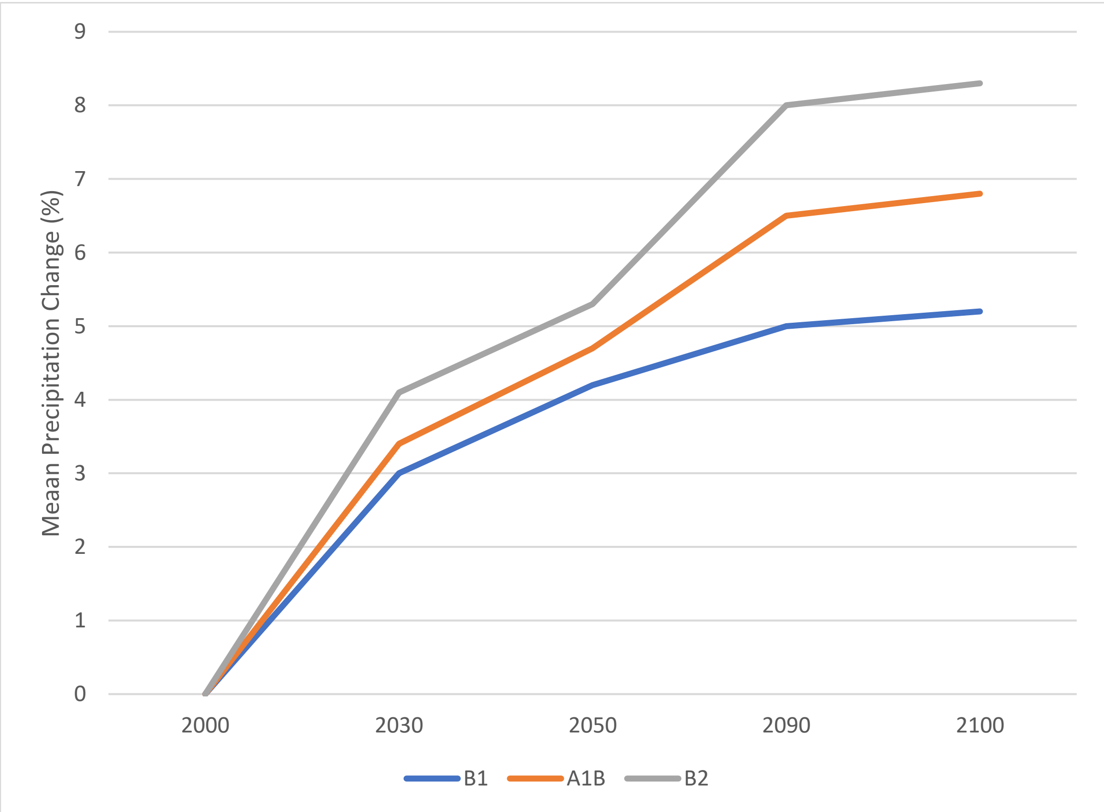
Providing downscaled, individual Pacific nation, projections for MSC stakeholders, considers each island experiences significant variations in precipitation frequency, duration and intensity as a direct consequence. Variations in long-term risks i.e. precipitation, influence the probability of flooding occurring. The degree of precipitation can influence sudden risks from increased kinetic energy (Clark, Mullan and Porteous 2011). Average annual precipitation ranges from 1200-2100mm (Figure 4.10). From local data and Pacific Climate Future, model projections, (Figure 4.12), the future impact of mean precipitation is expected to increase from a 0 baseline in 2000 for all three scenarios to a 1% increase under a B1, 3.4% (A1B) and 4.1% (A2) scenarios by 2030. By 2055, mean precipitation is expected to increase by 4.2% under a B1, 4.7% (A1B) and 5.3% (A2) scenarios; accelerating to 5% under a B1, 6.5% (A1B) and 8% (A2) scenarios by 2090-2100. Figure 4.13 projects historic, average SLR. Average SLR is anticipated to increase by 0.5m for a B1, 1m for an A1B and 2m for an A2 scenario.

Figure 4.11: Cook Islands Climate Change, Projected Mean Temperature Rise



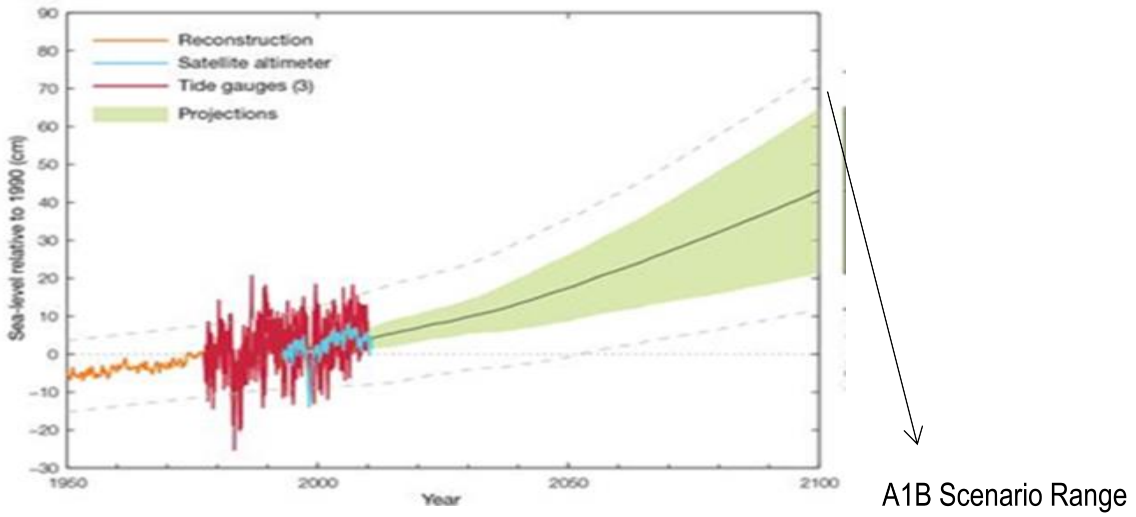
Source: Author

Figure 4.12: Cook Islands, Climate Change, Projected Mean Precipitation Rise



Source Author:

Figure 4.13 Cook Islands Climate Change, Observed and Projected Mean SLR



4.5.2. Implications for MSC Stakeholders in the Pacific Region

Providing projections further emphasises the need to prioritise Pacific MSC adaptation to climate change. Physical survival risks are considered to exceed the global average (Kim *et al*. 2015; Jia *et al.* 2015; UNISDR 2015). Downscaling projections to individual Pacific islands enable MSC stakeholders to consider how divergences between islands, might require adapting business operations, commodity production, risk management, training and strategies for each stakeholder, MSC stage, island, commodity and risk, in answering KRQA-KRQC. Other risks identified in section 2.2.3 affect physical risk exposure; including changes in event duration, intensity and frequency. These are influenced by local changes in precipitation, SLR, temperature and other variables for countries e.g. the Cook Islands, Fiji and Vanuatu (SPC 2013; SPREP 2014; WMO 2015b). This improves upon sources which only project regional level, economic impact of climate change e.g. Walsh *et al.* (2013) and Paeniu *et al.* (2015). This ignores local and region specific, impact event parameters are influenced by climate, geography, ecosystems economic activity, emissions, legal and coastal protection.

Climate change projections and information presented earlier can particularly aid MSC stakeholders to identify risk (KRQA) and the extent of impact costs (KRQB). It can aid capacity building, risk and adaptation response prioritisation, (CSR Asia 2011). It helps to efficiently direct funding, allocating scarce resources towards enhancing commercial adaptation and reduce maladaptation (KRQC). Projections can reduce uncertainty over when climate change will occur, where supply chains are physically vulnerable, what types of disruption risks exist and which processes are vulnerable Stakeholder adaptation can be more efficiently incorporated into risk management, cost benefit analysis and other thesis identified methods. Neumann *et al.* (2000), Hay (2011) and Codiga and Wager (2011) consider the value of providing SLR information at a local and regional scale. This could assist local governments, aid agencies and all stakeholders to direct resources, effort and attention in ascertaining risks and prioritising pre and post-event adaptation (Maddox 2013(. This resolves the frequently cited issue of asymmetrical information to stakeholders e.g. Simpson *et al.* (2013) who consider: How do projections translate into risks, opportunities and associated costs relevant to specific stakeholders and research locations?

4.6. INTERNATIONAL LEGISLATIVE RESPONSES TO CLIMATE CHANGE

To address ARQI, this section identifies the adaptation constraint; associated with legal uncertainty over the most appropriate, related legislation to minimise regulatory compliance costs for Pacific MSCs. This section summarises the main global (section 4.6.1) and Pacific, legislative responses (4.6.2) through current climate change and disaster risk management legislation. In response to the previously identified legal and technical, compliance impact costs (Section 2.5.3); it seeks to reduce stakeholder uncertainty to assist adaptation. The above projections identify significant impact costs involved in ignoring existing legislation and guidelines, based on projected acceleration trends of global, regional and single Pacific Island, climate change. Section 4.6.3 advocates current voluntary, legislative guideline approach remains inadequate and ineffective for global stakeholders. It proposes enforcing specific, integrated, climate change adaptation and disaster risk management legislation as an additional adaptation solution for KRQC. Including accurate projections along with specific MSC examples; can further assist Pacific and other nations to implement principles contained within conventions, country joint plans and legislative guidelines summarised below.

4.6.1. Current Climate Change Legislation

The United Nations Framework Convention (UNFCCC) was introduced in April 1999 and updated in 2012. It represents the most significant legal convention committing nations to mitigate potential sources of climate change through specific gas emissions, reduction targets. According to UNFCCC (1999 page 4), the parties aware of potential risks and impact costs commit to stabilising atmosphere gas concentrations ‘at a level that would prevent dangerous anthropogenic interference with the climate system.’ This needs to occur within *‘a reasonable time horizon that does not interfere with food security or economic development.’* It argues scientific uncertainty should not prevent action, based on the precautionary principle of minimising potential costs and risks where possible. The UNFCCC and its April 2016, Paris COP21 successor is ratified by 197 parties as the first globally, legally binding, climate change legislation for sovereign nations. It proposes adaptation through cooperation in research, information, communication, technology sharing, establishing environmental conservation and national emissions inventories across all stakeholders. This thesis interprets this to include MSC stakeholders.

Despite the potential threat to the future of economic activity and international MSCs including trade, there is no equivalent international legislation prompting nations to endorse or formally commit to climate change, adaptation policies. Nothing exists to secure the future of ports, transport, supply chains and trade (Pratt and Govan 2010; UNISDR 2013; Stavins *et al.* 2014). Transport emissions are specifically exempt from COP21. Nor does the UNFCCC (1999) formally commit developing nations to the same pressure as developed nations to reduce emissions. No international climate change legislation equivalent is identified that commits individuals, academia, media, NGO's, religions and the commercial sector. Nothing binds to prioritise climate change mitigation, adaptation, retreat or ecological rehabilitation response strategies. IAPH has primarily responded to climate change through its own voluntary legislative guidelines: The World Ports Climate Declaration (Van-der-Laar 2014). This aims to reduce CO_2 emissions and promote renewable energy. However, it ignores other greenhouse gases, sound environmental and pollution reduction management and commits only to mitigation rather than specific adaptation measures. Yet it serves as the most significant representative forum for port authorities.

The extent to which global and Pacific MSC stakeholders continue to underestimate risks (SPREP and UNDP 2015), is emphasized through no specific equivalent climate change declaration guidelines for stakeholders from producers to consumers, specifically committing to mitigation and adaptation policies (UNISDR 2015). No guidelines provide even greater risks to projected stakeholder survival, given the above projections. However, certain countries have voluntarily proposed the Hyogo Framework (UN World Conference on Disaster Reduction 2007), summarised below. This offers a form of risk management guidelines towards natural disasters. This section advocates Pacific MSC stakeholders adapt through implementing this framework ratified by all Pacific nations and specific measures proposed in other chapters. It provides legislative guidelines summarised below.

HYOGO Disaster Management Framework for Action 2005-2015.

I. Ensure disaster risk reduction is a national and local priority, with a strong institutional basis capable of effective implementation.
II. Identity, assess and monitor disaster risks and enhance early warning capacity.
III. Use knowledge, innovation and education to build a culture of safety and resilience at all levels.
IV. Reduce any underlying risk factors.
V. Strengthen disaster preparedness for effective response at all levels.

4.6.2 The Pacific Response to Global Climate Change

As this section outlines, those Pacific islands and governments most physically exposed have historically prioritised and continue to prioritise climate change since the earliest projections and studies (Pernetta and Hughes 1992). SPREP's Framework for Action on Climate Change was ratified as early as 2005, by most Pacific nations identified in Figure 4.14. More recently this legal commitment to implement climate change adaptation is affirmed in the 2009 Niue and 2014 Majuro Declarations, (PIFS 2012). This aspires to minimise significant, direct and indirect impact costs of climate change; not just to Pacific MSCs but entire islands. Unlike other parts of the world, especially developed nations continuing to underestimate potential risks; most Pacific Island nations have already individually formulated, official legislative measures (UNISDR 2015).

Examples include from Fiji's National Climate Change Policy (Fiji Government 2012) to Tuvalu's National Strategic Action Plan for Climate Change and Disaster Risk Management 2012–2016 (Government of Tuvalu 2011). It includes Kiribati's National Framework Plan for Climate Change and Climate Change Adaptation (Government of Kiribati 2007). These plans integrate long and short-term, risks, (primarily through disaster risk management). They consider associated impact costs and adaptation strategies, similar to this thesis's proposed research approach. These include stakeholder requirements (section 2.3). Individual nations are already working towards coordinated, response strategies with the main representative associations and aid agencies. This reduces scarce resources, labour and other constraints. Tonga and the Marshall Islands have created Joint National Adaptation Plans. The Cook Islands, Niue, Nauru and Tuvalu are evaluating potential adaptation plans (Cook Islands Government 2012). There is also a Pacific Plan for Strengthening Regional Cooperation and Integration (SPC 2014).

However; most of these policies have limited direct application for Pacific MSC stakeholders to identify and manage potential risks by adapting to impact costs. Existing climate change and disaster risk reduction, legal plans generally concentrate upon these costs and risks for individual and regional Pacific economies; rather than specific adaptation guidelines for each MSC stage (Rongo and Dyer 2015). This lack of guidelines as a significant constraint to adaptation further motivates this thesis. Current efforts mostly consist of voluntary guidelines on emissions mitigation, sustainable development, environmental management and disaster risk reduction response management, rather than specific inclusion of climate change adaptation. Being voluntary, these are seldom binding or effective at reducing potential emissions. These characterise the responses of SPREP's Pacific Resilience Programme and its 2015, Regional Environmental and Social Management Framework from pre- to post-event for mitigation. SPREP'S Framework for Action on Climate Change endorsed the following principles as early as 2005 illustrating the legislative commitment of all Pacific Islands to prioritise risks and implementing adaptation measures.

I Implementing adaptation measures.
II Improving governance and decision making.
III Improving understanding of climate change.
IV Education, training and awareness.
V Contributing to global greenhouse gas reduction.
VI Financing partnerships and cooperation.

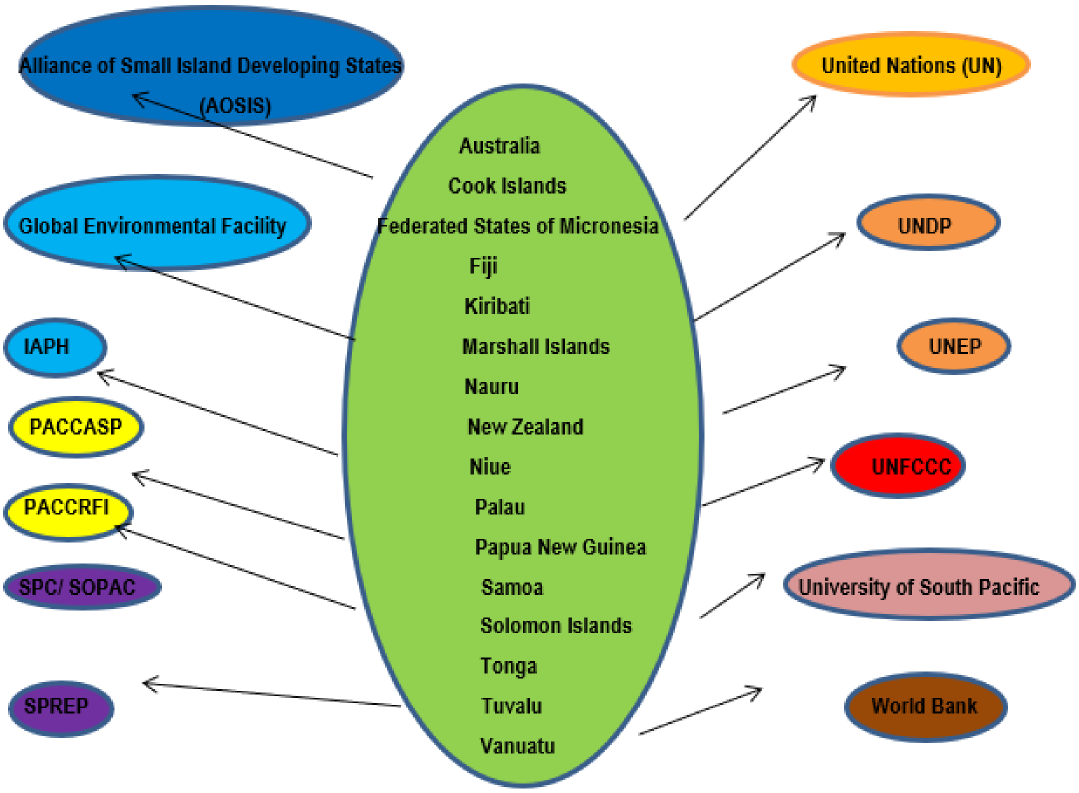
Niue Declaration on Climate Change

In contrast to other nations, the 2009 Niue Declaration emphasises a common legal consensus of Pacific Island nations to mitigate and adapt to climate change, (PIFS 2012). Its governments and populations are increasingly aware of the physical, economic and environmental risks presented. Yet it only contributes 0.03-0.06% of global emissions (AGBM 2014). These consequences clearly threaten the economic and physical survival of Pacific and other low altitude nations. This declaration appeals to other global nation, stakeholders to prioritise climate change through specific immediate, mitigation and adaptation actions. These include improving meteorological services and early warning, forecasting capacities. They include synchronising and improving information rather than just legislation. It seeks developed nations' assistance to expand Pacific capacity to resolve financial and other adaptation constraints; given other problems of poverty, environmental and underdevelopment. It also calls for those with capacity to accept the responsibility to act. Figure 4.14 illustrates Pacific stakeholders' commitment in prioritising through participation in economic, social, political and environmental organisations signed in the November 2014, Majuro Declaration. This is signed in a response to growing concern about the increase in gas inventory levels exceeding 400 ppm (9 May 2013). As section 4.2 outlined, global, climate change consequences, still commit to a minimum of 1-2ºC increase in global, mean surface temperature (B1 scenario) by 2100. This occurs even if emissions ceased.

However, no equivalent Pacific legislation, convention, voluntary guidelines or adaptation plans are identified formally committing Pacific nations to prepare for climate change implications on shipping. No formal plans exist for other forms of intermodal transport or MSCs, to minimise potential disruption consequences. This further increase information uncertainty for stakeholders seeking to identify risks, impact costs and potential adaptation solutions. SPC's 2011 'Framework for Action on Transport Services,' focuses only on the following 7 themes. These aim for sustainable, integrated, safe and accessible Pacific transport. Despite potentially providing the greatest challenge to achieving these objectives: these factors ignore climate change.

1. Leadership, governance, coordination and partnerships.
2. Capacity development, policy, planning and regulatory frameworks.
3. Transport safety and security.
4. Improved access.
5. Environmental impact, technology and energy.
6. Transport data, information and knowledge.
7. Sustainability, monitoring and evaluation.

Figure 4.14: Pacific Nations Membership of Major Organisations Prioritising Climate Change



Source: Author

4.6.3. The Inadequacies of a Voluntary Legislative Guideline Approach for Global Stakeholders

Despite the significant uncertainty of projected climate change; Stavins *et al.* (2014) notes that nothing formally legally binds any stakeholder to action. Nothing provides any major punitive measures against nations and no legal consequences exist for private sector MSC stakeholders, including individuals, who fail to mitigate or adapt. A voluntary, guideline framework approach has not only failed to reduce emissions, but emission levels have significantly increased, (as projections confirm). Its ineffectiveness is verified by this growth rate and increasing levels of environmental threat, despite increasing climate change awareness indicated in Luick (2010), Inoue (2012) and Rongo and Dyer (2015). From reviewing the above sources, it appears existing purely voluntary legislative, guideline approaches for global supply chains is completely inadequate in contributing to effective action on mitigation and adaptation. The implications in profoundly altering or destroying entire Pacific MSCs, resources and islands; need greater legislative commitment to prompt action.

These dangers occur even where risk reduction provides obvious benefit to survive commercially, for ecosystems to function effectively and for Pacific, East Indian Ocean and Caribbean nations to physically survive. For example, Australia Shipowners Association (2009) proposed a voluntary emissions, cap and permit trading scheme. The scheme also failed to reduce emissions or truly internalise externality costs. Existing legislation has failed to provide any significant deterring penalties or legal compliance costs, sufficiently punitive to deter evasion. Stakeholders evade from issues of moral hazard and risk-averse, short term behaviour, rather than long-term maximising profits for stakeholders. Few national governments have prioritised important, fiscal and other incentives from producer to consumers. Few stakeholders proactively endorse and implement climate change adaptation solutions. As observed in Chapter 2, few global and Pacific regional ports have specific guidelines or port adaptation plans (Wiltshire 2014; Becker and Caldwell 2015). Many MSC stakeholders are not prioritising effective action, (BSR 2014; CSR 2011) and are electing to worsen emissions and risk exposures. This is true particularly in the southern hemisphere; via port expansions from Rio de Janeiro to Durban, Mombasa and Melbourne, without considering climate change (Dyer 2015).

Climate change is considered to be an abstract future concept by these stakeholders, countered by mitigating or offsetting CO_2 emissions. It lacks prioritisation. However, the projections outlined in this chapter and scientific reports (IPCC 2015) emphasise the significance of this world peril to the future survival of Pacific and other nations' MSCs. In particular, the Pacific and Oceania suffer proportionally more than countries of higher elevation or greater capacity to resist. To fully and effectively adapt, this thesis proposes a new sustainable development approach. This would outline and enforce the rights, obligations and responsibilities of each MSC stakeholder to reduce their impact on the land, coastal and ocean environment. It supports a legal and regulatory adaptation approach with training for pre and post-events and institutional capacity. This is important given developing country constraints, rather than merely physical engineering solutions often preferred by stakeholders. Apart from the above policies, myriad proposed adaptation plans and policies further complicate legal compliance costs for any MSC stakeholder. Many simply seek to prioritise specific, policies at minimal expense.

This thesis advocates global MSC stakeholders seeking to adapt to climate change could prepare joint, national, adaptation plans of actions incorporating all stakeholders. These would not be restricted to governments and NGOs but media, academics, the community, international alliances and the private, commercial sector. Pacific nations' responses generally include overall adaptation policies; integrated, coastal zone management and disaster risk reduction or response policies. This minimises duplication of scarce resources (Stavins et *al.* 2014). Legislatively, other nations could learn from Pacific nations in Figure 4.14, through ratifying and implementing existing legislation. They could propose additional legislation to overcome a globally inadequate response. They could stringently enforce the polluter pays principle. Each proposed legislation could consider this and the precautionary principles, to incentivise adaptation and mitigation. Each nation could provide a source to finance adaptation and ecological rehabilitation, following previous models presented by AOSIS (2015) and the 2009 UN Committee for Pacific Island, Developing States. The IPCC (2014a) recommend any potential legislation or policy guidelines can be assessed for performance through its environmental effectiveness. They could evaluate impact on aggregate, economic performance; distributional impact, (equity between developed and developing,) and institutional feasibility, (social, cultural, technical, political and labour, along with enforcement and legal capacity).

4.7. SUMMARY

This chapter provides projections and the Pacific, Climate Change Futures, electronic tool for stakeholder adaptation. These provide the background for further research and analysis needed to address the intensity, duration and frequency of risk events. It identifies information and legal risk uncertainty of stakeholders with minimal, regulatory compliance costs. These present adaptation constraints, requiring legislative policy reform. The failure of BRICS, USA and Australia to implement substantial emission reductions and prioritise adaptation, (despite Europe's significant efforts,) requires further effort. Inaction ensures an increasing, projected risk of extinction for Pacific islands, economies and interconnecting MSCs. The risks and impact costs presented by projections to answer KRQA and KRQB; further indicate the need to adapt via increased research, collaboration, communication, awareness training and physical adaptation solutions including early warning systems. These are necessary to increase capacities to adapt and enhance resilience to ultimately survive at minimal disruption cost.

CHAPTER 5: PREDICTING CLIMATE CHANGE RISKS: HOW AWARE, RESILIENT AND VULNERABLE ARE PACIFIC MARITIME SUPPLY CHAIN SYSTEMS, STAGES AND STAKEHOLDERS? – THE COOK ISLANDS.

5.1: INTRODUCTION

This chapter presents empirical research to identify, evaluate and prioritise gradual and sudden climate change risks throughout Pacific maritime supply chain (MSC) stages and across a MSC system for stakeholders. This answers Key Research Question A (KRQA), the method conceptual framework in Chapter 3 and impact cost analysis in Chapter 6. KRQA enquired: ***'****What are the current and projected disruption risks for Pacific Island MSCs, from climate change consequences?'* It applies the previously devised risk-vulnerability, survey and analytical framework, utilising the Cook Islands as a specific case study. As Section 1.5 outlined this chapter identifies the Islands' background information in terms of demographics, MSC, environment/ecosystem and climate in section 5.2. To address climate change risk identification (Stage II), descriptive statistics of stakeholder profiles and survey results for risk perceptions of Pacific MSC stakeholders are analysed in Section 5.3 (Appendix I). Data collected was statistically analysed for reliability and validity. It presents time series data (Appendix VII) which calculates the historic probability of a related risk occurring. It projects future risk events for maritime commodities based on localised projections in Chapter 4.

Section 5.4 provides a vulnerability-risk analysis across an MSC, (Stage III). It presents survey findings for each MSC stage; incorporating quantitative and qualitative results related to climate change risks. Interview content analysis provides factors affecting the probability of occurrence, risk and vulnerability, based on specific risk events. Providing a practical method application further verifies the validity of this thesis' conceptual and analytical framework's over existing method limitations, summarised in section 5.6. This assists Pacific maritime and global supply chain, stakeholders including governments, researchers, businesses and individuals with limited resources and significant constraints, in climate change risk prioritisation, (section 5.5, Stage V).

5.2: COOK ISLANDS CLIMATE, CLIMATE CHANGE AND MARITIME SUPPLY CHAINS

The Pacific Ocean (Figure 1.1) covers over 155,557,000 km^2 of ocean territory with (8,497,017 km^2 land area) and 38,039,400 people (UNESCAP 2016). Yet global and localised, climate change risk consequences extend beyond individual stakeholders and supply chains, within dependent island territories and 17 sovereign states. They study differs from existing land-centred climate change impact studies are land centred by emphasising the maritime sector. This forms the centre for Pacific and global trade, resources, economies, ecosystems and supply chains. With limited land and natural resources, Pacific MSCs and island nations are vulnerable to other nations and ocean-spanning, seaborne trade route connections. The Cook Islands, (capital Avarua, Rarotonga Island), has been a self-governing, constitutional monarchy since 1965 and consists of 20,700 people. It extends over 15 coral atoll islands and 2 submerged reefs (Figure 5.1); with just 236km^2 land area but 2,200,000 km^2 of Pacific Ocean (SPC 2015). Its climate and climate change projections are summarised in Chapter 4. Its economy is dominated by pearls, fisheries, tourism and offshore banking services (detailed in Chapter 6). As Table 5.1 and Figure 5.3 summarise, it depends upon the ocean for MSC centred products including pearls and fish exports as 87.7%. Refined petroleum forms 25% of imports. The second highest imports are vessels/vehicles (4.7%). Third are iron structures (2.1%) to replace frequent coastal environment and adverse risk event exposure. Top 5 export trade partners are Japan, Turkey, Thailand, China and South Africa. Top import partners are New Zealand, China, Fiji, Australia and Turkey.

Figure 5.1: The Cook Islands

Source: Cook Islands Government 2016.

Table 5.1: Cook Islands Trade Overview 2015

GDP $* million	Exports (Type)	Value $*	% Exports	Imports (Type)	Value $*	% Imports
309.23	Total	34,000,000	100	Total	143,000,000	100.0
	Fish	20,040,000	60	Petroleum	35,900,000	25.1
	Pearls	9,418,000	27.7	Vessels/vehicles	7,860,000	5.5%
	Citrus fruit	476,000	1.4	Iron Structures	2,950,000	2.1%

Source: Author

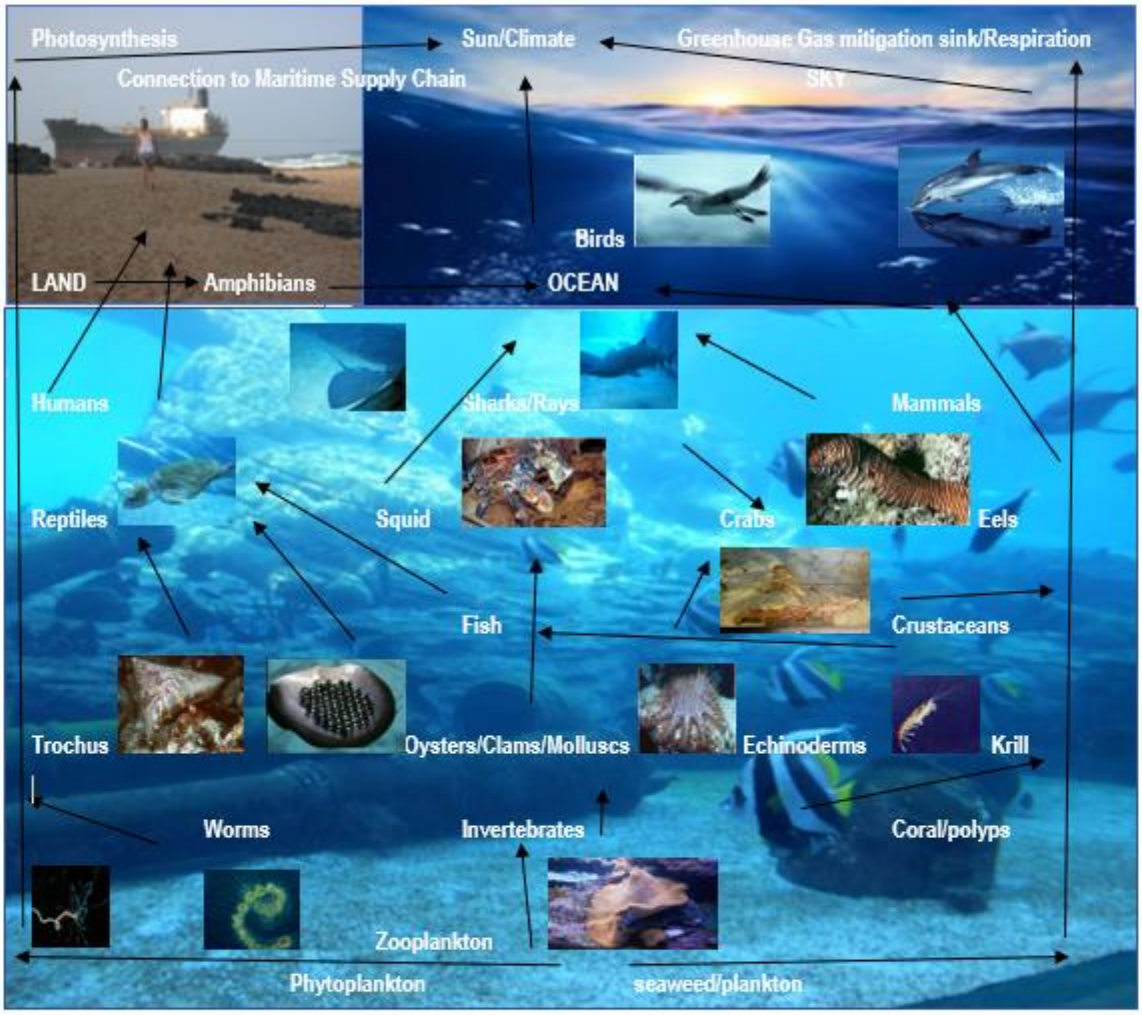
Figure 5.2 illustrates a Pacific maritime ecosystem similar to the Cook Islands. Table 5.2 summarises ecosystem, ecological and economic functions. The Islands' environment includes extinct volcanoes, coral reefs, atolls and seagrasses. As with other MSCs its ecosystem contributes to economic activity through sand formation for beaches, coral reef formation for coastal tourism, physical island formation and wave energy, dispersal barriers. These offer natural resilience against sudden risks. They influence the quality, quantity, habitats and survival of interconnected, maritime and other terrestrial resources for fisheries, forestry, mining, jewellery and other economic activities. The region is the home for 1 trochus, 66 seaweed, 83 seabirds, 2 squid, 5 ray, 19 shark, 20 reptiles, 22 maritime mammals, over 664 fish and 232 crustacean species. It includes 109 echinoderms, 539 molluscs, 70 clam/6 giant clam, 11 oysters and 34 eel species. This excludes plants, coral reefs and land-based ecosystems, which this thesis considers directly or indirectly influence MSCs and tourism activity.

Table 5.2: Ecosystem Functions for MSC Economy Stakeholders

Ecological	Economic
Biomass/Biodiversity Life Formation and Habitat	Life, Food, Material
Conservation	Supply of Natural Resources, Reduced Imports
Biological/Physical/Chemical	Redundancy against Uncertainty
Growth, Reproduction,	Trade, Production, Consumption, Income/Profit
Respiration/Oxygen/Photosynthesis	Greenhouse gas mitigation funding/source sink
Water supply/purification. Food security/Nutrition	
Protection	Protection –Vulnerability and Resilience
Ocean Chemistry, currents, salinity	Risk Identification, Monitoring, Prioritisation, Adaptation
Coral atolls –geographical physical formation, continued growth and survival	Risk Enhancement if Ignored –Legal, Reputational, Insurance, Security, Operational, Impact Costs
Sand formation, nourishment and sediment	Opportunity
Evaporation, Condensation and Absorption	Insurance against Maladaptation,
Climate Regulation –calcification, stratification	Future Sustainability and Survival
Counter eutrophication	Knowledge –Existing and Potential/Spiritual
Detoxification	Stability/Security/ Increased Adaptive Capacity
Population equilibrium	Aesthetic/Cultural/Social
	Tourism

Source: Author.

Figure 5.2: A Pacific Maritime Ecosystem/Pacific MSC Resources



Source: Author.

Figure 5.3 shows a typical Pacific MSC relationship from the maritime resources' ecosystem through beneficiation, extraction, transport and distribution, export via the port, shipping and ultimately to the consumer. This is further defined in section 2.1 and applies to the Cook Islands. Each stage forms a series of complex interconnections influencing other core species. In time this affects not only marine resources and environmental aspects but also potential economic growth, trade and development.

Figure 5.3: The Cook Islands Pacific MSC.

Source: Author.

5.3: RESULTS OF THE COOK ISLANDS STUDYS' SURVEY AND INTERVIEWS

To study climate change impact costs and adaptation strategies a field trip was carried out to assist with the data collection and interviewing of MSC stakeholders in the Cook Islands. The stakeholder sampling strategy is described in Section 3.4.4. The data collection and analysis below follow the methodology and research design stakeholders need to identify specific risks, presented in Chapter 4. Appendix VII summarises risk events based upon centralised, Pacific, time series data from 1900-2016. Identifying risks enables stakeholders to anticipate the probability of various events affecting them in a particular year, other time horizon or climate change scenario. It can calculate which risks are worth marginalising or avoiding, given finite resources Descriptive statistics possess advantages of reducing uncertainty and simpler identification of core, demographic/other factors, accurately summarising and organising large data samples. They provide central tendencies and measures of dispersion as presented in for example Salkind (2011); Fei (2009); Pateman (2016); Williams (2016). These statistical analyses evaluate common perceptions and factor results across stakeholder stages and risk types. This chapter's qualitative results utilise content analysis to cluster, thematically code and evaluate core factors affecting supply chain risk and resilience. This is identified in interviews via quotes and statistical analysis summaries based on the questionnaire (Appendix V).

5.3.1: Participants' Demographic Profile:

263 stakeholders were contacted. 63 presented invalid email addresses, 9 were absent during the field research period, 3 rejected participation and 6 offered excuses. One indicated participation, conditional upon reaching Mangaia Island. Four were recruited from other contacts. Several were recruited from researcher publicity via Cook Islands Herald, Radio, TV and Parliament, reducing response bias. This research included 59 Cook Islands interviews and 99 surveys producing a relevant, focused sample size of 99 and response rate of 37.64% (131 non-responses). Survey respondents are named 1-99. Interview respondents are classified I-LIX. Table 5.3 indicates a diversity of survey question types to obtain data. On average 3 reminders were sent. Many only confirmed participation when personally approached, indicating scepticism of online surveys. Respondents received access to a research report and web link to overall thesis as incentives to participate. The mean survey completion time was 27 minutes. Interviews ranged from 17 minutes to 2 hours 28 minutes, with a mean time of 47 minutes, indicating significant interest. Stakeholders satisfied statistical face validity tests, including all questions and receiving responses indicating significant internal consistency over climate change awareness for the 5 Likert scale questions. Of 15 experts, 12 indicated agreement, producing a content validity ratio of 0.75 for Lawshe's Test. Correlations support convergent and discrimination validity and therefore content validity.

Table 5.3: Stakeholders' Survey Information

Question Type	Number
Likert Scale Questions	5
Multiple Choice/Ranking	7
Open Ended Questions	15
Yes/No/Fixed Response	10
Total	37

Source Author

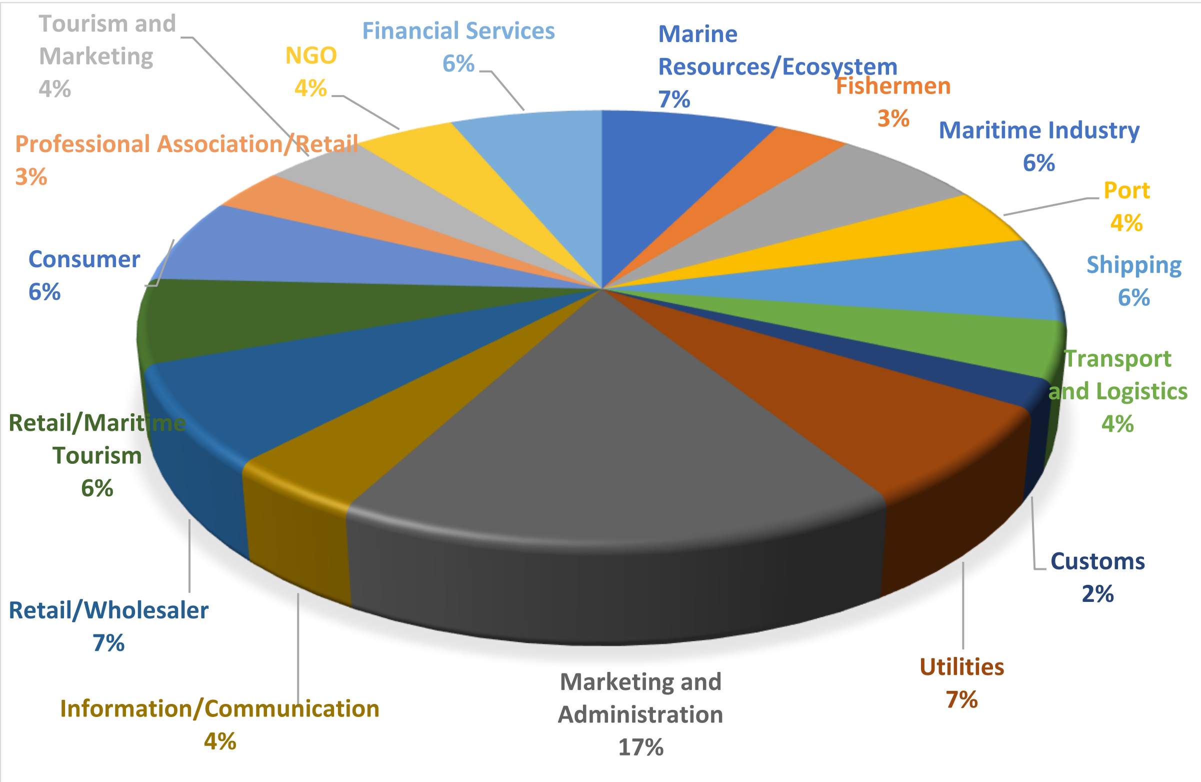
Table 5.4: Descriptive Statistics of Survey Questions 6-10

Question	Minima	Maxima	Mean	Variance	∑Var	σ^2	Skewness	Kurtosis
6	3	5	4.093	0.515917	4.031027	20.85749	1.051	-0.529
7	3	5	4.34	0.4356	4.031027	20.85749	1.088	1.027
8	1	5	4.195	0.648025	4.031027	20.85749	-0.674	5.052
9	1	5	4.0085	0.983072	4.031027	20.85749	-0.155	1.812
10	1	5	3.7965	1.448412	4.031027	20.85749	0.422	2.156
K = 2								

Source: Author.

The demographic profile of participants across a MSC presented in Figure 5.4 Descriptive statistical results are presented graphically to analyse specific demographic variations in the Cook Islands in Figures 5.4-5.7. Interview questions and participant information appear in the Appendices. The figures derive from Appendix I-V, Section A Questions and participant information in Appendix V Section B. Marketing and administration had the highest response rate at 17%. This is attributed to the majority of marine tourism operators and government ministries being concerned about climate change, officially mainstreamed into government policy. In contrast, individuals (6% consumers, 3% fishermen) and smaller private sector operators participated less, lacking resources and frequently preoccupied, as observed globally. Certain stakeholders such as customs (2%) and ports (4%) had only a few employees. Most operators, even government ministries employ 10 people or less, indicating high reliability, validity and willingness, despite labour, time and other resource constraints.

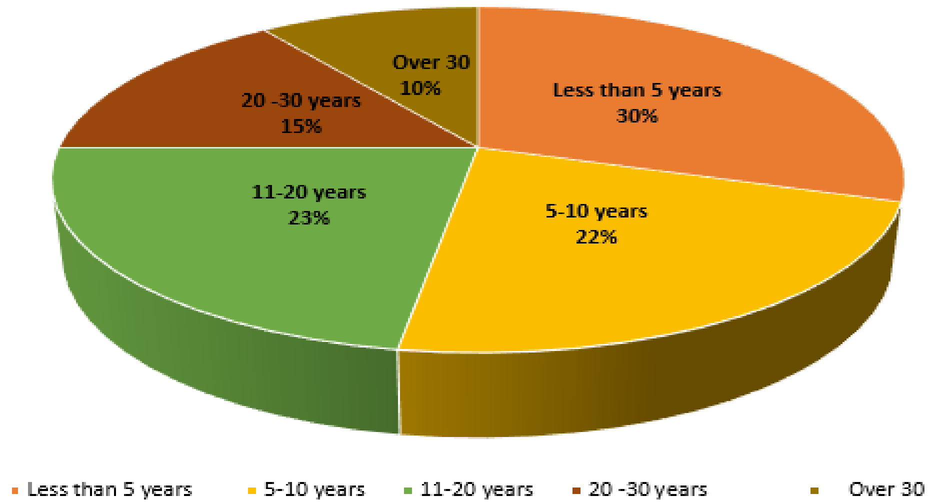
Figure 5.4: Cook Islands MSC Participating Stakeholders Demographic Profile



Source: Author.

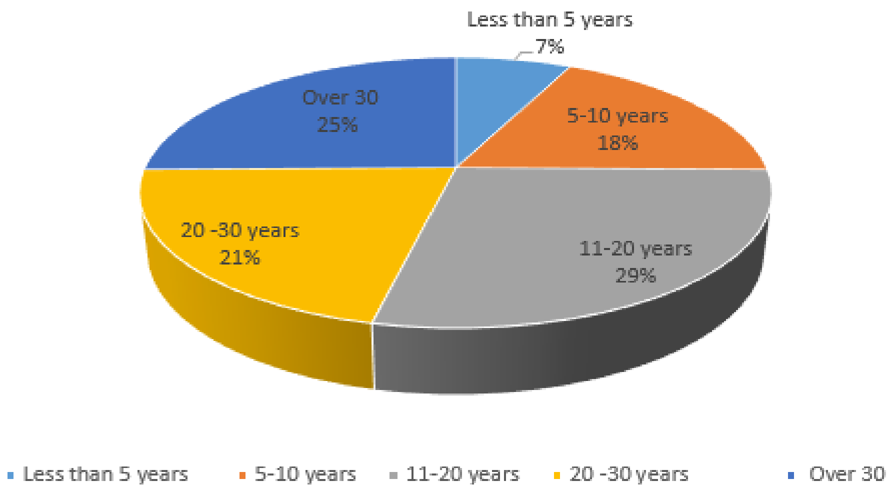
Figure 5.5 shows most participating stakeholders had experienced at least 2 major cyclones and 1 drought in their present role (34% 5-10 years' experience). However, the next highest proportion (28%), were less psychologically prepared with one or no event and less than 5 years' experience. Only 22% were really conscious of historic impacts. The average organisation however was more resilient and familiar, with 21.16 years existence and 75% over 10 years' experience (Figure 5.6). Only 7% experienced no cyclones. To enhance the validity and accuracy of psychological risk expectations, the sample specifically recruited qualified professionals (24%) for technical aspects in Figure 5.7. 68% of respondents had a degree/diploma or higher to sufficiently understand the research objectives. The few secondary education qualified candidates were experts e.g. pearl farmers and fisherfolk/consumers directly perceiving climate change risks, and increasing their psychologically awareness and willingness to participate.

Figure 5.5: No of Years Stakeholder Participant Experience



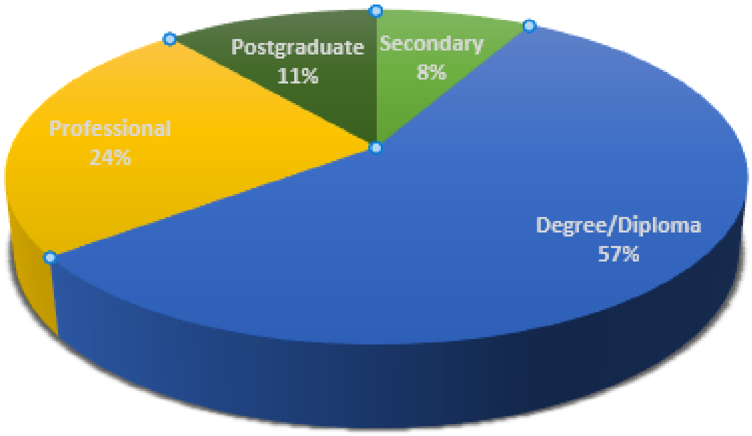
Source: Author.

Figure 5.6: No of Years Company is Established (2018)



Source: Author.

Figure 5.7: Stakeholder Participant Education Qualifications



Source: Author.

5.3.2: Climate Change Risk Awareness and Perceptions.

To answer KRQA, participants were asked 5 5-point Likert scale questions assessing their awareness of climate change risks (Question 1), impact costs (Q2), adaptation solutions (Q3), policies/legislation (Q4) and funding sources (Q5). The mean value is higher than the midpoint for all questions (Table 5.5) suggesting reasonable familiarity with climate change, further enhancing the reliability, validity and consistency of the method and results. High awareness of perceived risks and costs can be attributed to education and experience. This is further verified when assessing specific risk perceptions against time series data for actual risk events. In contrast, values converging to the average or midpoint indicate greater priority should be devoted not to general risk education and training but towards understanding policies and obtaining funding for adaptation.

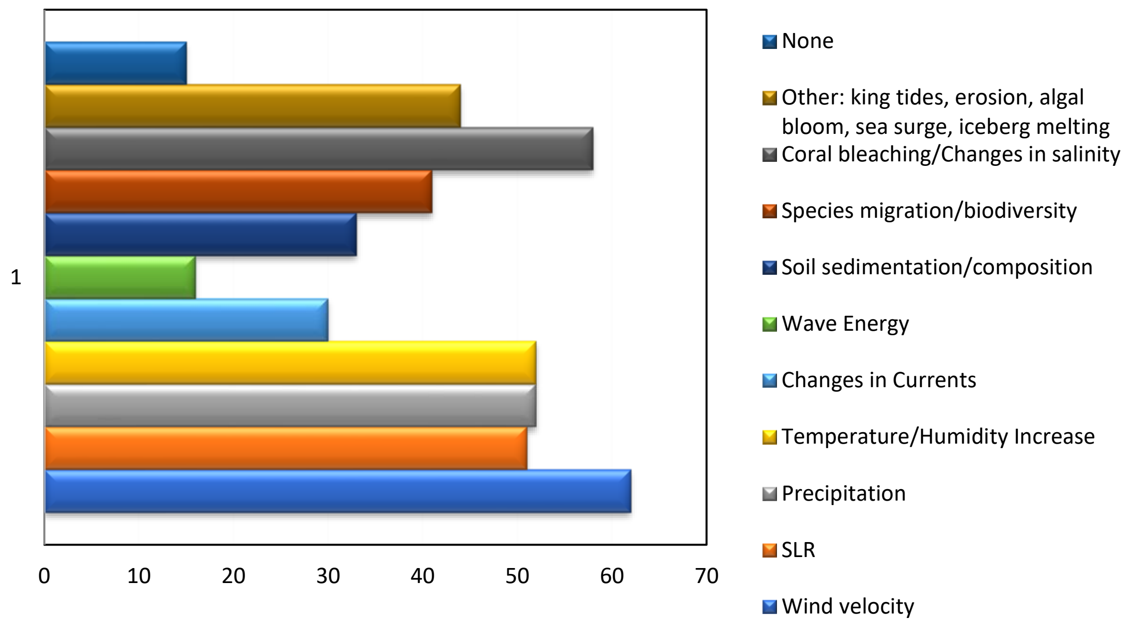
Table 5.5: Stakeholder Perceptions of General Climate Change Risk Awareness

	Survey Weighted Average	Interview Weighted Average	Joint Weighted Average
Question 1	4.375	3.186	3.781
Question 2	4.275	3.680	3.978
Question 3	3.600	3.390	3.495
Question 4	3.150	3.067	3.109
Question 5	2.800	2.593	2.697

Source: Author.

This. It hypothesises Cook Islands and other Pacific stakeholders are willing to climateproof and adapt based on their risk perceptions and experiences. Figure 5.8 illustrates various long-term, risk perceptions for Cook Islands, MSC stakeholders. Of a sample size of 99, 62 (62.6%), perceived wind velocity as most significant, followed by coral bleaching (58) and precipitation (52) These were attributable to high recognition of the contribution of coral reefs to marine tourism, ecosystems and aquaculture, whilst wind and precipitation were often traced to concerns about cyclones and storms. In contrast changes in currents, waves and species received less priority, often from a lack of interest, knowledge or identified direct impact.

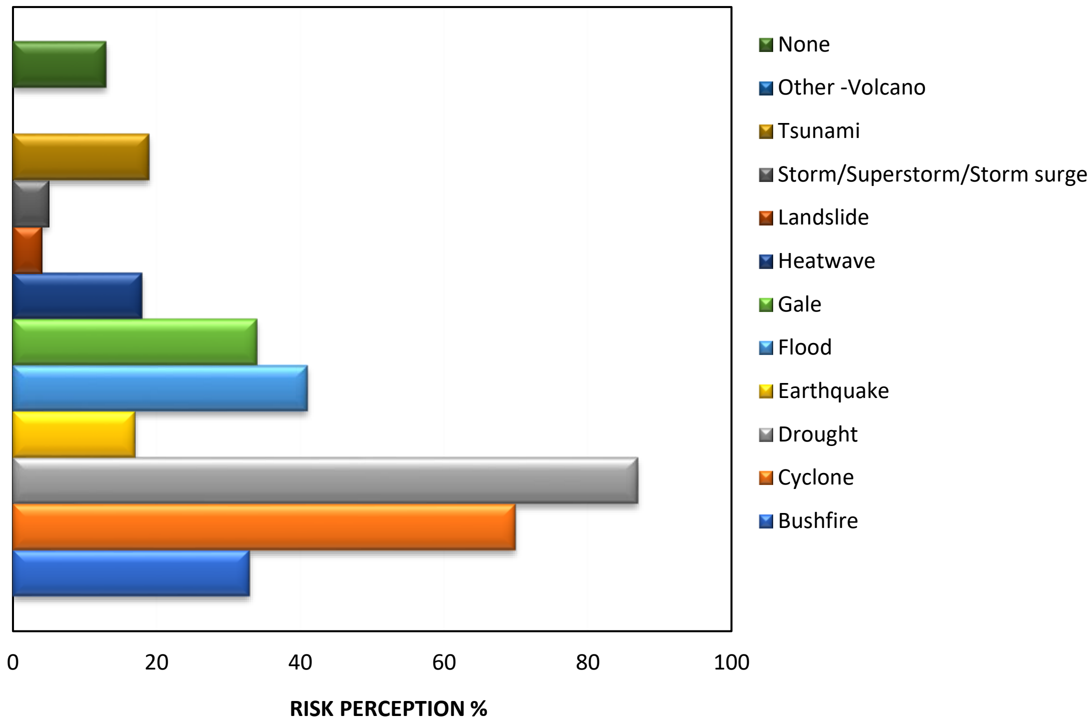
Figure 5.8: Cook Islands MSC Stakeholder Long Term Risk Perceptions



Source: Author.

Figure 5.9 highlights short-term, climate change risk perceptions. Droughts received 87 (98.9%) as the foremost concern, with one respondent not identifying any risk concerns. Cyclones followed for 70 stakeholders (68%), and 34 indicated gales. Earthquakes with 17, landslides with 4 and a surprisingly low 5% for storms; were perceived as far less probable. Risks remained consistent across the type of stakeholder interviewed. Conversely out of 66% of stakeholders aware enough to pinpoint other long-term risk concerns, none identified any additional short-term events. This was possibly due to uncertainty as to what constituted a long-term risk or natural disaster.

Figure 5.9: Total MSC Stakeholder Interview Short Term Risk Perceptions

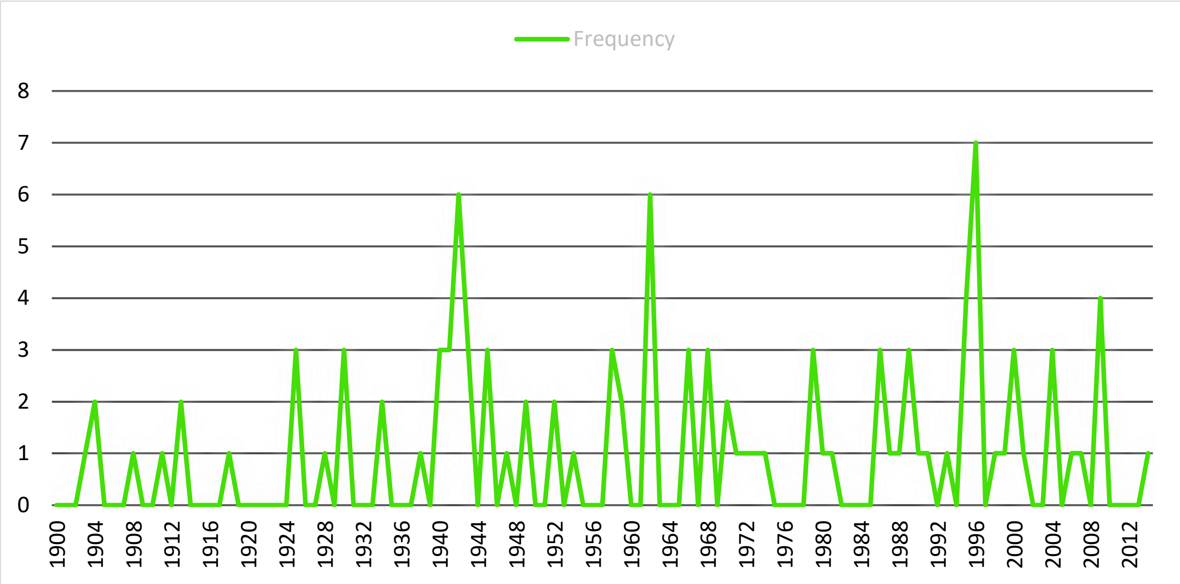


Source: Author.

5.3.3: Historic and Future, Climate Change Risk Identification for a Pacific MSC (Stage II)

This section provides climate change risk events using time series data for the Cook Islands in Table 5.6 using information gathered from field research, various academic and government records. Appendix VIII provides data for 17 Pacific MSCs. This calculates a historic risk event's probability using Equation A in Table 5.7. For example, the probability no events will occur in any given year is 39.44% (0.3944) irrespective of risk type. It calculates a future risk event's probability in Table 5.8. Based on projections, the minimum expected probability (p value) of at least 1 cyclone in 2020 increases to 26.09%. (0.2609). This addresses KRQA, indicating which risks are projected to be most significant for MSC stakeholders. A comparison with perceptions in Figures 5.8 and 5.9 indicates the extent to which risk can be accurately determined. The Chi square test statistic $\chi 2.$ = 0.9307. As the test statistic is smaller than the critical value, then the null hypothesis of following the Poisson distribution is not rejected. The data also indicates a trend of an increasing frequency of average risk events over time (Figure 5.10) although not calculated for specific risk types. Cyclones and storms have increased in duration (Figure 5.11) not just in impact and intensity. Cyclones and gales are among the more frequent events. Although only 2 historic droughts had been recorded, an astonishing 57% of stakeholders perceived this as the most significant risk. This was possibly overestimated because both droughts occurred recently (within the past 8 years). Several stakeholders were concerned with bushfires, tsunamis and earthquakes, far more than their historic occurrence suggested. Fewer risks were underestimated, aside from storms.

Figure 5.10: Cook Islands Frequency of Risk Events Over Time



Source: Author.

B = Bushfire, C = Cyclone, D = Drought, E = Earthquake, F = Flood, G = Gale. H = Heatwave, S = Storm, T = Tsunami. Source: Author collected from myriad various secondary and primary sources.

Table 5.6: Cook Islands Short Term, Climate Change Risk Events

Historical Pacific Climate Change Risk Chronology Cook Islands			
Year	**No of Risk Events**	**Date (For Information Available)**	**C/S Average Risk Event Duration (No of Days)**
1900…			0
1904	C	1/01	1
1905	S, C	06/03	1
1909	S	7/02	0
1910…			0
1912	C	12/02	1
1913			0
1914	S, C, T	14/05	1
1915….			0
1919	E	6/06	0
1920…			0
1926	S, C	T -31/03; S/C -16-23/11	7
1927…			0
1929	C		1
1930			0
1931	S, C, S+C	4/02	1
1932			0
1935	S, C	10/03	1
1936…			0

1939	D	05-08	0
1940…			0
1941	S, C, S+C,	13-19/01; 19-26/02	6
1942	S, C, S+C	13/02;	6
1943	2S, 2C, 2 (S+C)	06/03;	1
1944	S, C, (S+C)	31/01	1
1945			0
1946	S, C, (S+C)	13/14/01	2
1947…			0
1948	C	13-14/07	1
1949..			0
1950	2C	01	5
1951..			0
1953	H, S, T	H-07-09	0
1954…			0
1955	H	07-09	0
1956			0
1959	S, C, S+C	11-16/02	3
1960	H, T	T- 22/05/1960, H- 06-09	2
1961			0
1963	2S, 2 C, 2 (S+C)	07/03/1963, 12-14/03	2
1964	H	6/09	0
1965…			0
1967	2S, C	16/12	1
1968…			0
1969	2C, H	11-25/03, 27/02-6/03	12
1970…			0
1971	H, G	17-19/12	0
1972…	C	22-28/03	6
1973	H		0
1974	H		0
1975	H		0
1976			0
1980	2S, 1 G	G-23-28/02	0
1981	S	17-24/03	7
1982	G	25/02-06/03	0
1983			0
1987	S, C, S+C	28/12-05/01/	8
1988	H		0
1989	C	22-28/02	6
1990	S, C, S+C	13-18/02, 30/11-04/12, 06-13/12	7
1991	S	15-19/03	5
1992	S	12-16/02	4
1993			1
1994	S	14/02	1
1995			0
1996	H, C, S, (S+C)	07-17/01	10
1997	2H, 2C, S, G, S+C	S- 06-10/12/, C- 07/11/, C-24-28/12, G-21-25/04	5
1998			0
1999	H		0
2000	H		0
2001	S, C, F	F-5/12, C-03/12, S-29/11-03/12	1
2002	C	06-11/02	5
2003			0

2005	5C	3-8/02, 10-17/02, 28/02-05	6
2006			0
2007	H		1
2008	H		1
2009.			0
2010	T, E, C, S	T/E-13/04, S-11/02, C06/02-10/02	4
2011…			0
2015	D	25/02-31/12	0

Source: Author collected from myriad various secondary and primary sources.

Table 5.7: Historic Climate Change Risk Probabilities for Cook Islands MSCs

Expected Probability of a Cook Islands Climate Change Related Risk Event: 1900-2015					
Total Average No of Events = 107	**λ =0.9304**	**Landslides = 0**	**λ = 0**	**Drought = 2**	**λ = 0.0435**
P(X=0)	0.3944	P(X=0)	0	P(X=0)	0.9828
P(X=1)	0.3669	P(X=1)	0	P(X=1)	0.0171
P(X=2)	0.1707	P(X=2)	0	P(X=2)	0.0001488
P(X=3)	0.0529	P(X=3)	0	P(X=3)	1.854E-07
P(X=4)	0.0123	P(X=4)	0	P(X=4)	3.75E-08
P(X=5)	0.002291	P(X=5)	0	P(X=5)	1.3061E-11
Bushfire = 0	**λ = 0**	**Tsunami = 2**	**λ = 0.0435**	**Earthquake = 0**	**λ = 0**
P(X=0)	0	P(X=0)	0.9828	P(X=0)	0
P(X=1)	0	P(X=1)	0.0171	P(X=1)	0
P(X=2)	0	P(X=2)	0.0001488	P(X=2)	0
P(X=3)	0	P(X=3)	1.854E-07	P(X=3)	0
P(X=4)	0	P(X=4)	3.75E-08	P(X=4)	0
P(X=5)	0	P(X=5)	1.3061E-11	P(X=5)	0

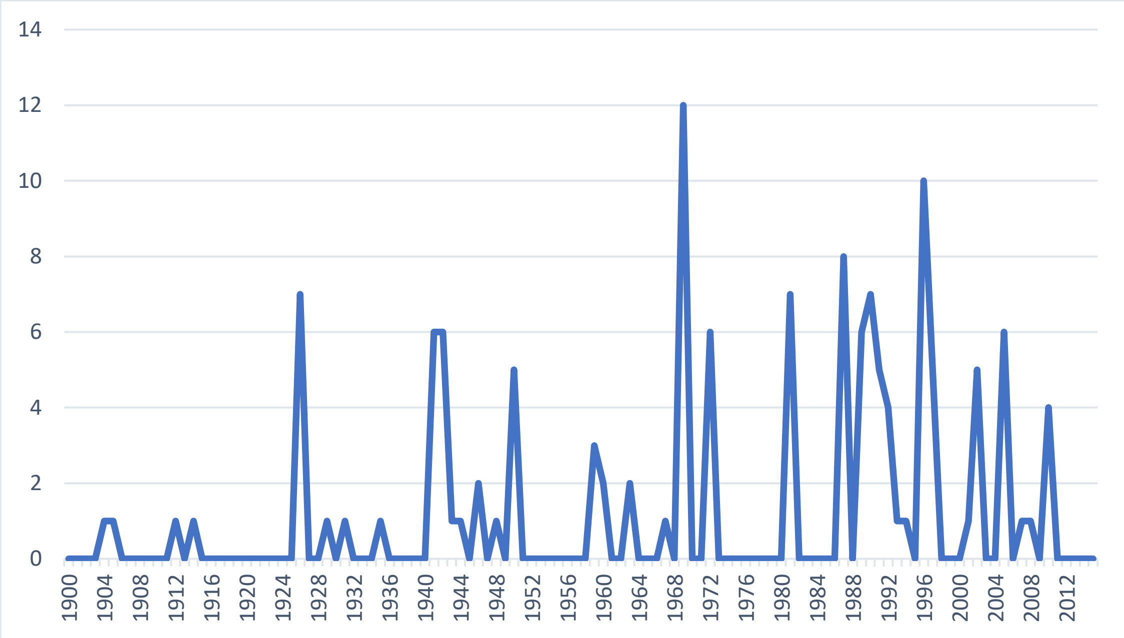
Source: Author collected from myriad various secondary and primary sources.

Table 5.8: Predicting Current/Future Climate Change Risk Event Probabilities for Cook Islands MSCs

	Current	**2017**	**2018**	**2019**	**2020**		**Current**	**2017**	**2018**	**2019**	**2020**
F, E, B (1)	λ = 0.0867					**Storms = 29**	λ =0.2522				
P(X=0)	0.9913	0.9833	0.9753	0.9673	0.9593	P(X=0)	0.7771	0.7691	0.7611	0.7531	0.7451
P(X=1)	0.0088	0.0168	0.02488	0.03288	0.04008	P(X=1)	0.196	0.204	0.212	0.22	0.228
P(X=2)	0.0000375	0.0000375	0.0000375	0.0000375	0.0000375	P(X=2)	0.0247	0.0247	0.0247	0.0247	0.0247
P(X=3)	0.000001088	0.000001088	0.000001088	0.000001088	0.000001088	P(X=3)	0.002078	0.002078	0.002078	0.002078	0.002078
P(X=4)	2.366E-10	2.366E-10	2.3664E-10	2.3664E-10	2.366E-10	P(X=4)	0.000131	0.000131	0.000131	0.000131	0.000131
P(X=5)	4.178E-13	4.178E-13	4.1775E-13	4.1775E-13	4.178E-13	P(X=5)	0.00006607	0.00006607	0.00006607	0.00006607	0.00006607
Future	**Current**	**2017**	**2018**	**2019**	**2020**		**Current**	**2017**	**2018**	**2019**	**2020**
D (2)	λ = 0.0435					**Tsunami (2)**	λ = 0.0435				
P(X=0)	0.9828	0.9748	0.9668	0.9588	0.9508	P(X=0)	0.9828	0.9748	0.9668	0.9588	0.9508
P(X=1)	0.0171	0.0251	0.0331	0.0411	0.0491	P(X=1)	0.0171	0.0251	0.0331	0.0411	0.0491
P(X=2)	0.0001488	0.0001428	0.0001428	0.0001428	0.0001428	P(X=2)	0.0001488	0.0001428	0.0001428	0.0001428	0.0001428
P(X=3)	1.854E-07	1.854E-07	1.854E-07	1.854E-07	1.854E-07	P(X=3)	1.854E-07	1.854E-07	1.854E-07	1.854E-07	1.854E-07
P(X=4)	3.75E-08	3.75E-08	3.75E-08	3.75E-08	3.75E-08	P(X=4)	3.75E-08	3.75E-08	3.75E-08	3.75E-08	3.75E-08
P(X=5)	1.3061E-11	1.3061E-11	1.3061E-11	1.3061E-11	1.3061E-11	P(X=5)	1.3061E-11	1.306E-11	1.3061E-11	1.3061E-11	1.3061E-11
Future	**Current**	**2017**	**2018**	**2019**	**2020**		**Current**	**2017**	**2018**	**2019**	**2020**
H (17)	λ = 0.1478					**Cyclone (36)**	λ = 0.313				
P(X=0)	0.8626	0.8546	0.8466	0.8386	0.8306	P(X=0)	0.7312	0.7232	0.7152	0.7072	0.6992
P(X=1)	0.1274	0.1354	0.1434	0.1514	0.1594	P(X=1)	0.2289	0.2369	0.2449	0.2529	0.2609
P(X=2)	0.009422	0.009422	0.009422	0.009422	0.009422	P(X=2)	0.0358	0.0358	0.0358	0.0358	0.0358
P(X=3)	0.0004642	0.0004642	0.0004642	0.0004642	0.0004642	P(X=3)	0.003737	0.003737	0.003737	0.003737	0.003737
P(X=4)	1.715E-05	1.715E-05	0.00001715	0.00001715	1.715E-05	P(X=4)	0.0002924	0.0002924	0.0002924	0.0002924	0.0002924
P(X=5)	5.07E-06	5.07E-06	0.00000507	0.00000507	5.07E-06	P(X=5)	0.00001831	0.00001831	0.00001831	0.00001831	0.00001831
V	λ = 0					**Gale = 5**	λ =0.0435				
P(X=0)	0	0	0	0	0	P(X=0)	0.9524	0.9444	0.9364	0.9284	0.9204
P(X=1)	0	0	0	0	0	P(X=1)	0.0416	0.0496	0.0576	0.0656	0.0736
P((X=2)	0	0	0	0	0	P(X=2)	0.0009059	0.0009059	0.0009059	0.0009059	0.0009059

Source Author.

Figure 5.11: Cook Islands Cyclone/Storm Risk Event Average Duration No of Days



Source: Author

5.4: CLIMATE CHANGE VULNERABILITY-RISK ANALYSIS FOR A COOK ISLANDS MSC

5.4.1: Climate Change Risks to Maritime Resources and Ecosystems.

As section 5.2 emphasises, an effective risk-vulnerability framework recognises ecological capital and ecosystem roles in serving functions identified in Table 5.2 for a Pacific MSC. Analysing specific risks provides indications of where they exist and which can be managed. It identifies the risks that cannot be sustained, need prioritising and the extent of ecological capital costs caused by climate change. Stakeholders were divided into categories with divergent extent of risk awareness, concerns and impacts. Section 5.3's risk perception survey indicated they had a certain risk awareness for ecosystems. None had considered implications for their own operations. They ignore the need to integrate ecosystems as effective risk management and resource security for MSCs. Given low market prices for consumers and existing environmental pressures, the maritime ecosystem remains undervalued, relative to potential risk and impact cost aversion. Notably international financial/insurance services ignored the historically successful role of coastal asset protection, where ecosystems were valued. International companies were particularly ignorant. Even those with resources to adapt, lacked concern about potential risks to Pacific ecosystems and their future resources. Attitudes focused more on prioritising long-term events (higher mean response rate of 41 stakeholders); than considering sudden risk pressures (28). This undermines maritime resource survival for production, aquaculture, individual or other supply chain operations.

Only 0.2% of the world possesses coral reefs, yet these are home over 33% of all global marine biodiversity and ecological capital. The Cook Islands provide a major Pacific, MSC case study. Its capital island Rarotonga is encircled by reef. With Kiribati it possesses among the planet's largest EEZ's of maritime terrain and potential resources. Risks include increased ocean acidification and salinity, salt spray pressure, coral bleaching and disease, SLR, and higher sea surface, land and air temperature rises. These contributed to coral reef areas declining 30% from the 1990's to 2001 and further 6% by 2015. In the 1970's coral took 10 years to recover. In 1990's it took 21 years to recover. Repeated cyclones, SST, invasive species, reef bleaching and disease risk events from 1991-2014, (1991, 1994, 1995-1998, 2006, 2010, 2014) emphasise ecosystem vulnerability. MSC resource survival is threatened. As Respondent 31 states we have a self-interest critical role to serve the environment:

> *"With climate change, we face the eyes of devastation. What we hand over for our children is how we will look to them and history, that's why we must serve and act. We must believe in making things better for ourselves, future generations, our environment and the planet. It's always important and will always remain important.'*

To address KRQA, Table 5.9 identifies the most significant Cook Islands maritime resources specifically affected by Pacific risks. A reef survey noted climate change and other existing pressures have influenced a dramatic decline in the species listed from 1970-2015. Lagoon temperatures reached 31º. Predator porcupine fish, invasive Indian mynahs and sharks provide an exception, indicating species migration. In 2012 the Islands declared a shark sanctuary, increasing numbers. Stakeholder content analysis emphasises how risks affect maritime ecosystems. The Islands marketing approach emphasises guardians of pristine lagoons and islands with a 'Ridge to Reef strategy' aiming to preserve this scenic paradise (Respondent 8). However, the crystal-clear lagoon experienced a recent algal bloom growth. Unusual species have invaded including hundreds of stonefish and mud crabs. Decreasing species numbers and habitats threaten future MSC commercial resource security for production, beneficiation, aquaculture and remaining stages and stakeholders. Yet each species is worth investing in as ecological capital; given existing commercial demand and future potential research. 20 species possess value, favoured as ornamental/aquarium fish (UNFAO 2010).

Table 5.9: Cook Islands Risks and Maritime Ecosystem Species Decline 1970-2015

Species Freshwater	**Cook Islands Location**	**Climate Change/Variability Risk Impacts**
Whitebait	Rarotonga	Extinct from droughts–formerly favoured floods
Dusky sleeper	Mangaia, Atiu, Mauke	Droughts
Western gambusia	Rarotonga	Drought/Drained swamp
Tilapia#	Mangaia, Atiu, Mauke	Increased sediment/siltation/Drought
Freshwater eel	Rarotonga, Avatiu	Drought, increased salinity
Marine species		2000 Februa virus, 2002 oyster blight, 2012 algal bloom
Hatchet/Giant seahares	Mangaia, Rarotonga	Drought/ changes in species migration/loss
Lined seahare	Mangaia, Rarotonga	Droughts/change in biodiversity
Serrated swimming crab	Aitutaki, Rarotonga	Coastal erosion
Coconut Crab	Mangaia, Rarotonga	Preferred delicacy, coastal erosion, soil sedimentation
Sargassum	Mitiaro, Atiu, Mangaia	Cyclones, storms, tsunamis
Tangled hair seaweed	Mangaia, Rarotonga,	Cyclones, storms, tsunamis
Sea grapes	Atiu, Aitutaki, Mangaia,	SST
Sponge seaweed	Mangaia, Rarotonga,	SST,
Seagrass parrotfish	Mauke, Mitiaro, Atiu	Change in species migration and biodiversity
Scribble/Silver rabbitfish	Mauke, Mitiaro, Rarotonga	SST, Air, SLR, Flooding
Forktail rabbitfish	Mauke, Mitiaro, Rarotonga	Increased ocean acidification
Rudderfish	Mangaia, Mitiaro, Mauke	**Marine Reef Fish Affected include**
Fringelip/ warty lip mullet	Atiu, Aitutaki, Rarotonga	Marbled grouper
Marbled/brown cod	Mangaia, Rarotonga	Yellowfin goatfish
lunar tail/peacock cod	Mangaia, Rarotonga	Barracuda
Brown moray	Mangaia, Rarotonga	Convict/Black/Yellowfin surgeonfish
Red snapper	Rarotonga, Atiu	Mackerel scad
Rose mouthed turban	Mangaia, Rarotonga	Bull's eye
Branching coral	Rakahanga, Manihiki	Green triggerfish
Winged mussel	Rakahanga, Manihiki	Orange spotted emperor
Black lipped pearl oyster	Rakahanga, Manihiki	Napoleon wrasse
Trochus, Giant clam	Rarotonga	Big eye bream
Brown pencil urchin	Mangaia, Mitiaro, Mauke	Topsail drummer
Star shaped limpet	Mangaia, Mitiaro, Mauke	Unicorn fish
Pelagic		5 Banded parrotfish
Reef sharks	Aitutaki, Rarotonga	Squirrelfish
Skipjack/yellowfin tuna	Mangaia, Mitiaro, Nassau	

Source: Author.

The above species and Figure 5.2 ecosystem are further expected to decrease rapidly in numbers, sizes and quality due to changes in SLR, PH and precipitation predicted in Chapter 4. From 1980-1999, average Cook Islands SST was 26.5ºC. Coral with maximum temperatures of 25-29ºC have resilience limits, which collapse, as with other maritime ecosystems. PCCASP, SPC and SPREP (2015) project further coral area losses of 25-65% by 2030, 50-75% (2055) and 90%-100% by 2100 unless reefs are restored. Other risks include altered species migration and reduced biodiversity. ENSO has already affected skipjack tuna migration as a key MSC staple. Catch rates, quality and size have significantly decreased. These are projected to initiate a 20% reduction in nutrient supply, producing fewer zooplankton, algae and primary biomass, and lower coral cover/slower recovery rates; which affects all other species. The lower the biodiversity, the more significant the existing species in preserving the functionality and value of local ecosystems. Demersal fish are projected to decline by 5-20% by 2030 and 20--50% by 2050 for A1B IPCC scenarios. Pelagic fish are to decline by 10-30%. Giant clam/green turtles, invertebrates, pearl, trochus, clam, milkfish and marine ornamental are projected to decrease by 50% 2035 and 90-100% by 2100; as coral dependent species under A1B, (business as usual) scenarios (SPC 2015).

Without recovery and prioritising future ecological capital, maritime resources decline. This increases extinction rates as catches unsustainably increase, multiplying ecosystem pressure further. Stakeholder 11 indicated the following concerns:

> "*Species migration and biodiversity, as we are a nation that relies on fish for food security and foreign earnings. Ocean acidification as it can impact coral and shelled mollusc health. Soil composition as increased soil salinity affects crop growing abilities. Wave energy as this is the biggest potential impact to our foreshores and coral reefs. Precipitation as we may suffer more intense droughts. Currents bring nutrients and may affect migration patterns."*

Respondent 77 surmised "*Coral reefs and ocean chemistry are key building blocks for life. Climate change will lead a new ecosystem to evolve at the expense of the old."* Increased ocean currents, turbulence, and wind velocity combine to provide rougher conditions, exposing existing delicate species such as algae and crustaceans to further pressure. Terrestrial ecosystems and supply chains are similarly affected. Participants noted changes, including mangos blooming earlier in July whilst apples and other, less temperature resistant fruit, have stopped germinating. It is proposed affected stakeholders utilise sources when checking risks to maritime ecosystems and species. They can ascertain which are rarest, most vulnerable and most crucial for MSCs. This prioritises conservation, resources and reserves with eco-agencies, local community and government stakeholders.

The future of Pacific maritime resources for MSCs are further threatened by existing environmental pressures across supply chain locations and small-island states' constraints. Cook Islands constraints include pollution, over-fishing, over-development, sensitive habitats, subsistence lifestyles, overpopulation, shore vegetation removal, competing land use, waste dumping, coastal erosion and physical topography. It includes beach sand mining and limited freshwater supply for atolls. Mangaia, Rarotonga and Aitutaki lagoon contamination accelerates climate change risks further. Volcanic islands with limited arable land areas, soil fertility, and low crop yield and productivity increase dependence on coastal fisheries. Draining wetlands for taro production lowers biodiversity and flood protection. Lacking environmental reserves and sustainability, Cook Islands ecosystems are significantly constrained in satisfying future MSC performance, revenue, resilience and production requirements. This increases potential impact costs (Chapter 6), whilst multiplying risks to subsequent production and beneficiation/manufacturing stages. Without managing fisheries and agriculture, stakeholders will lack resources to ensure future production, income and recovery from long and short-term ecosystem risks.

Without renewing resources, the Cook Islands and other Pacific nations' adaptive capacity will be increasingly unaffordable. Nor will they be able participate in global MSC activities, lacking minerals, fuel and other products. This may necessitate even more economically unsustainable aid. More exposed, coastal developing nations face collapsing ecosystems, economies and submerged land areas from higher instability, unless risk is pre-empted by increasing natural mitigation systems. A significant flaw of established risk management theory is that it ignores not only climate change risk uncertainty, but also the status and sustainability of underlying ecosystems providing resources. It is proposed that, before undertaking any supply chain risk assessment, existing environment conditions are considered prior to evaluating risks to future resources. This ensures future prosperity, sustainability, and ultimate survival. Active risk monitoring, identification, analysis and adaptation should extend to ensuring marine and terrestrial ecosystems remain functional and thrive. Therefore section 5.4 provides among the first supply chain and risk management studies to assess climate change risks to resources and whether disruptions are temporary or permanent. It establishes a first stage to measuring risks to producers.

5.4.2: Risks to Producers

Producers play a critical role in the Cook Islands MSC driving the economy and meeting the demand for goods and services. The total 2016, Cook Islands population was 17,459 with 14,974 residents in 4,372 dwellings. 1,855 dwellings exist as producers/resource extractors with 1,151 in Rarotonga, 244 in the Northern Islands and 661 in the Southern Islands. This is summarised in Table 5.10. Of these stakeholders, 1,031 are more vulnerable to reef and lagoon risk pressures; 114 to ocean risks and 710 are influenced by neither. Climate risk events are expected to disrupt producers through various impact costs to maritime resources, infrastructure, equipment, transport, operations and people. Examples include subsistence/community, domestic and international commercial, mixed and recreational fishing. Risks reduce income/profit levels directly and present indirect threats to food security.

Table 5.10: Cook Islands MSC Stage Producers Overview 2016.

Location	Total no of dwellings	Non-fishing	Subsistence	Mixed	Commercial	Recreational
Rarotonga	3,154	2,203	852	27	72	49
South Islands	939	278	561	9	91	25
Aitutaki	482	175	246	9	91	7
Mangaia	170	30	127	9	52	5
Atiu	137	45	78	0	13	0
Mauke	92	19	65	0	15	5
Mitiaro	58	9	46	0	8	8
North Islands	279	36	236	0	3	54
Palmerston	13	2	6	0	7	0
Pukapuka	109	13	88	0	5	5
Nassau	13	0	13	0	0	5
Manihiki	78	8	170	0	0	44
Rakahanga	21	3	18	0	0	0
Penrhyn	53	10	41	0	2	0
Total	4,372	2,517	1,649	36	170	138

Source: Author adapted from 'Cook Islands Census 2016.'

Content analysis from the questionnaires/interviews evaluates specific risk consequences, which directly threaten navigation and production/extraction, aside from potential damage to shore infrastructure, vessels, equipment, ecosystems and stakeholders. Lower tides increase exposure for subsistence fishermen who increasingly need motorised boats to access catches, affecting species. Droughts pressurise water supply, increase salinity/ocean acidification and nutrient supply threatening species. Bushfires do not affect producers or other stakeholders. Volcanoes/earthquakes and tsunamis occur infrequently across the Cook Islands but can worsen sea conditions, acidification and salinity. Unlike previous Pacific research concentrating on a localised area or main island, this thesis considers risk identification to producers and other stages across all 15 Cook Islands. Producer risk perceptions were challenged to be statistically valid with only 3 fishermen willing to be directly interviewed due to reluctance to allocate time away from harvesting, despite actual risks.

Questionnaire content analysis reveals how susceptible fisheries can be (Respondent V):

"*Storms and cyclones lead to loss of stock and business generation as well as outright destruction of property. Cyclones and coral bleaching events disturbing coral reefs are also followed by ciguatera fish poisoning; meaning we have not been able to harvest reef fish on the main island of Rarotonga since the 1990's. We have to import fish instead," "It creates local food security issues, which forces the islands to rely more on the importation of food goods at high retail prices affecting our livelihoods."*

Food security pressurises other supply chain aspects indirectly, creating further external dependence for economic activity. Respondent XXXVII:

"It impacts on agricultural yields and has the ability to increase vector borne diseases, including the downward flow of lagoon sedimentation, SLR and changes in current and wave energy. This impacts maritime industry from local fishermen to national and international shipping suppliers. It also increases the rate of coastal erosion and natural flushing cycles within lagoons. These impacts can also affect the growth of biodiversity and potentially increase the rate of invasive species,"

These factors influencing vulnerability are frequently cited by stakeholders. Stakeholder 6 comments:

"*Some islands are affected by king tides, saltwater inundation – crops, increased tropical cyclones and longer drought periods. The Cook Islands relies on coral reefs as a nursery and habitat for fish, increased pH levels and warmth levels. This largely impacts on fishing communities relying on this food supply for their household and trade. It forces fishermen to travel further out into the ocean to catch fish, adding extra financial burdens on a person to maintain an outboard motor and fuel supply, which can be very expensive."*

Maritime ecosystem interviewees (XVII/XVIII) indicate multiple risk pressures observed for fisheries including degraded water quality and a vastly increasing range of dead coral reef. Stakeholder 92 mentioned how cyclones damaged clam hatcheries, coral fish life and the marine environment. Lagoon risk monitoring is limited to 3 islands (Rarotonga, Aitutaki and Manihiki). Stakeholder 95 mentioned delays to fishing practises, until risk events were over and fragility of boats, charters cancelled and business properties stabilised. Whilst marine tourism operators and the retail sector have observed no significant changes in fisheries supply, producers are extending their range in response to be more resilient. Many echoed interview XL in considering themselves very aware of climate and climate change, needing to reduce emissions, recognising deteriorating water conditions, fish species behaviour changes, SLR, altered currents and disturbed nutrients. These affect subsequent MSC stages in providing stock for aquaculture, exports and marine tourism. However, Respondent 40 did indicate, *"a noticeable decline in certain species catches exists but it's challenging to tell whether this is pollution, human overfishing, climate change, all 3 or something else…"*

Even those involved in maritime security observed (XLVIII). "*We are getting more rain and the place is getting flooded. Coral is dying and we are getting a lot of erosion we cannot control."* With subsistence farmers the most observed effects were fisheries damage, (possibly storage/vessels transport/equipment), if not protected. These minor costs did not adversely affect other maritime stages in not contributing as net producers. However, these provide greater pressure and risks as net consumers, when unable to feed themselves. Respondent 70 stated: *"People who live on remote Pacific islands depend heavily on the ocean, marine resources and imports to feed themselves".* Recreational fishers differ in voluntary pursuits rather than surviving/contributing to economic activity except when with boat charters, depend upon the tourism industry. Yet these respondents had not even considered climate change risks, being particularly vulnerable. Stakeholders currently devote an average of 3.3 hours on 4 trips per month to sustain themselves. Whilst they had observed a decline in maritime resources, biodiversity and ecosystems changes, they had not conserved efforts. Mixed and commercial fisheries experience different risks to profits and costs as net contributors to other MSC stages and stakeholders, being highly dependent yet marginally more fiscal adaptive capacity. As maritime ecosystems collapse and risk events increase; distances, time and opportunity costs are further anticipated to rise. Those interviewed had previously experienced risk. Yet few have specifically adapted.

Larger enterprises were less involved in voluntary sustainable fishing practises or aware of risks to resources. Although better resourced, international companies were less interested in research participation (Figure 5.4), paradoxically indicating greater risk underestimation and inexperience. They were less aware of localised climate change implications with fewer years' experience. Despite high adverse risk consequences from collapsing ecosystems, those from the EU, USA and Asia were more likely to ignore indigenous community values of ecological capital/local experience. They did not share information or adaptation plans and had minimal stockpiling/reserves. Few could accurately determine the risk to their operations and supply chains; indicating the need for greater private sector priority. This has significant implications for the future of Cook Islands beneficiation and industry sector, resource security, performance, cost and revenue.

5.4.3: Risks to Marine Beneficiation and Aquaculture

The economic future of Pacific MSCs is also undermined by climate change risks to the utilizers, processors and artificial cultivators of maritime resources produced/extracted. As a small island nation, this sector has few stakeholders. However, it is so economically pivotal that it has a dedicated Pearl Authority, and dominates non-tourism exports (Chapter 6). The Cook Islands has 17 pearl farms in Rarotonga and 42 in the Northern Islands (38 in Manihiki, 3 in Rakahanga and 1 in Penrhyn). There is 1 marine equipment firm, 1 trochus hatchery, 3 government hatcheries (including 1 for pearls), 3 aquaponics, 2 clam producers, 3 ornamental aquarium fish and community/private sector projects in tilapia, seaweed and milkfish. Other industries including the agricultural, manufacturing, pharmaceutical, cosmetics, tourist and handicraft sectors also partially depend upon maritime resources. Of all supply chains the pearl sector has already experienced the greatest contraction of stakeholders and economic activity from 182 in 2000 to 59 in 2011, (pearl spat collector lines from 735 to 456). Only an estimated 12-15 are full time farmers, and members of the Pearl Farmer's Association. It still remains the highest industry earner of foreign exchange, second only to tourism.

All of the 6 survey respondents (6% of total sample population) and sector, were physically vulnerable to these risks. Specific risks aside from ciguatera fish poisoning include higher SST, wind velocity, ocean acidification and salinity, droughts, rainfall, changes in currents, coastal erosion, species migration and biodiversity. This reduces the formation of pearl nacre, quality, size and survival/growth rates; reducing profits, production output and increasing costs. The Ministry of Marine Resources is specifically committed to aiding pearl industry research, while the Pearl Authority targets marketing. Respondents indicated high awareness, directly experiencing risk. A pearl farm operates with 2-3 seedings and harvests each year. Pearls take from 18 months to 3 years to cultivate, hence significant gaps between harvesting and income further enhance vulnerability. Events have prompted a lagoon management plan and other efforts to ensure pearls remained. In 1997 Cyclone Martin destroyed 85% of aquaculture infrastructure including 15% of pearl production. However, stakeholders had low expectations, reducing output projections from risks. Pearls declined from 2,604,444 in 2000 to 889,221 in 2011 to 100,000 in 2016/2017, with an estimated maximum 300,000-400,000 lagoon production capacity. However, those interviewed expressed severe doubts the ecosystem, market and aquaculture would recover to previous levels of being ecologically and commercially viable/sustainable. They cited the 2000 Februa virus, 2002 oysters' blight, 2012 algal bloom and the2016 lagoon, SST increase to 31ºC. Respondent 14 identified that last year, they could not work with shells for 6 months –too warm and oysters too weak. When asked about future climate change for the industry, they were sceptical:

"I see the lagoon as less and less suitable for pearl farming. We cannot relocate here, have no lagoons further south. Aitutaki lagoon is too shallow. To produce pearls we have to stress the oyster. We need premium conditions for oysters to recover and the lagoon is mostly too warm – producing bacteria". "I don't see farming in 20 years' time unless we move lagoons, perhaps to places in Fiji suitable latitude".

Respondent XXX identified the ideas and experience of the Manihiki Pearl Farmers' Association to help pearl farmers, fishermen and maritime-based communities to cope with vulnerability and prosper during change/uncertainty. It is seriously considering closing down due to political interference, increasing vulnerability further. Respondent LXV was unusually sceptical of climate change; viewing it as a term to attract funding, be politically correct and describe natural phenomena that have always been a threat such as El Nino, La Nina and cyclones. He acknowledged the 1997 cyclone hardly affected his pearl farming business. Even if land infrastructure is ruined, pearl cultivation takes place underwater. He remained concerned about having experiences recorded, ensuring future business continuity and prosperity for children.

Many stakeholders became psychologically acclimatised referring to 5 major events, incentivising them to prioritise climate change from an actual risk event. These included Cyclones Sally in 1987, Martin (1997), 5 in two weeks (2005), Pat (2010) and a recent drought, as influential events in altering their risk perceptions. Cyclone Martin in particular, illustrated how unaware and under-prepared psychologically and physically stakeholders were. The population dropped from 650 to 240 residents. The pearl farm industry contributing the most economic activity for a decade; collapsed production from 200 farms to below 20. Pearls collapsed from 300-400,000 to around 10,000-30,000 per year by 2017. Respondent 24 emphasises this total loss that occurred when waves washed over the narrow island, taking everything out to sea. This included the loss of all equipment needed for pearl farming - lines, floats, spats, trestles, dive gear, boats, and seedling houses. He raised the psychological, social and financial impacts which prevented people from re-starting their businesses. Respondent 55 emphasised:

"*The most vulnerable cost is loss of equipment, infrastructure as well as morale and psychological strength to keep going. Infrastructure along the foreshore are most likely to fall during cyclone events."*

Factors influencing vulnerability indicated the following (Respondent 88):

"*Pearl oysters took 3 years to recover, lagoon hypoxia 10 years. Biodiversity loss affected natural food resources and pearls*. *A heatwave affected farm reduced my production each year by 20-50%. Industry on my island could disappear in 10-20 years' time."*

Respondent XXXVI warned: "*Development in high risk areas is really prone to natural disasters. Removing natural barriers or changing landforms has increased the risks as development continues to expand."*

Respondent XXX highlighted this major climate change awareness and the effectiveness of simplifying information for local communities and aquaculture. She pioneered science fairs to aid children to conserve marine environments and past stakeholder workshops including efforts to encourage a pearl meat sector as value processing. She attended international workshops to share experience. Respondent 71 listed reasons to be proactive:

> "*It impacts on economic revenue but also cultural practises of fishing and conservation. Because islands have very small populations, tropical cyclones mean that people have to assist with cyclone recovery so they have to leave their jobs to focus on these effects. Cyclone Martin in Manihiki forced a lot of pearl farmers to migrate to Australia, New Zealand and Rarotonga, meaning pearl farm production decreased.* R*esilience is ignored by the general public."*

Existing concern and risk awareness have prompted investment in aquaculture, to ensure a profitable future for maritime resources compared with ecosystem uncertainty for commercial fishing. Aquaculture is perceived to offer greater capacity in risk resilience, being able to regulate environment, inputs, outputs, quality, temperature and other variables. It provides potential in reducing pressures on wild populations from increasing human populations and demand for finite ecosystem resources. It offers potential via ranching to augment threatened wild species.

However, aquaculture might actually accelerate risks to existing ecosystems; where feed depends on capture from wild fisheries. Climate change also has potential economic impact costs to markets. Risks to physical infrastructure, populations, demand and supply, influence production costs, quality and quantity. Further uncertainty factors affect the quality, distributions, quantities, types and habitats of plant, coral and animal species. Producers may experience a competitive advantage in having greater capacity to control disruption effects, including element exposure and water management. The most significant risk includes the unknown fate of existing wild fisheries, which influences aquaculture as a competitor. The more uncertain the market supply or higher projected demand for maritime resources; the higher the price. Fingerlings and fish oil/feed become unsustainably extracted from seriously depleting global stocks, unless these inputs can be autonomously developed. This approach is a more cost and environmentally sustainable alternative. Both the producer and aquaculture/industry stages possess significant risks for MSC stakeholders. Although not consumed locally; aquaculture –particularly pearls - contribute towards exporters/importers, port throughput and other stages.

5.4.4: Risks to Seaports

Global MSC dependents often underestimate climate change as the greatest risk to future prosperity and survival, with few specific adaptation efforts. In contrast, the Cook Islands government, with decades of experience in climate change awareness, have particularly focussed on its ports; as the core infrastructure upon which trade and GDP are increasingly vulnerable. They are the centre of supply chain and economic activity. Although the private sector remains highly vulnerable and unadapted to projected risks; its ports have undertaken risk-vulnerability assessments and climateproofing adaptation strategies. Its port authority directly employs 167 stakeholders. However, all stakeholders both influence and remain influenced by related risks. 4% of respondents were from Ports.

The only international seaport, Avatiu Harbour is situated along with the majority of MSC assets and stakeholders, on Rarotonga Island's north coast in Avarua. It processes 95% of cargo, 100% fuel and 90% food imports. The 2 port channels provide gaps for the encircling coral reef as coastal protection and foreshore. Port assets are vulnerable at sea level, close to the ocean, within a floodplain and with limited coastal vegetation/trees to reduce surface runoff. During risk events, performance and output productivity significantly decreased, delaying port throughput and export volumes. Respondent 74:

> **"***All of the above risks increase port risks for vessels to enter the harbour or face extended delays until sea and wind conditions improve and safe to enter. Such delays affect the local economy and food security' Extreme risk events are of concern because it would damage wharf infrastructure."*

Wharf roads are directly by the port whilst stacking areas have no physical protection. This diminishes profits, production output and increases costs. Tables 5.11 and 5.12 emphasises Cook Islands seaports' vulnerability to specific risk events, based on survey and interview results.

Table 5.11: Avatiu Port Assets

Asset Type	Asset Age (years)	Condition/Vulnerability
Tugboat	7.5	open exposed; operational in 3-5 days if in water but hours if removed mobile with sufficient forewarning
Pilot boat	7.5	open exposed but only 1 no redundant capacity
Movable Boat cradle	7.5	Mobile, removable
6 person life raft	5	Mobile, removable
5 lifebuoys	4	Mobile, removable
Aluminium pontoon	4	Mobile, removable
1 Container cleaning stand	8	Mobile, removable
2 Trucks	12.5-11	Sea spray oxidation
3 Bikes	12-6	Mobile, removable
Engine chassis	4.5	Mobile, removable
1 40 foot spreader	13	Mobile, removable
1 20 foot spreader	10.5	Mobile, removable
19 Reefer points	12	SLR, wind, 3-5 days to recover.
3 3T, 1 12T, 1 32T, 1 35 T forklift	8-5	Mobile, removable
1 25 m light tower	9	Limited light
Solar navigation buoy/marine lights	8-5	Mobile, removable

Source: Author based on survey/interview estimates.

Factors influencing vulnerability include being at sea level, less than 500m from streams and limited coastal vegetation/wind protection. One port authority respondent considers climateproofing infrastructure has enhanced resilience:

> "*When they did the development; the final height was taken into consideration for sea surge, swell height and SLR. By saying that will not stop here at 0.5 metres. It's good to have all the information we need for risk assessments about this port and how it will affect the way it will operate in 20-30 years' time. But cyclones are getting bigger and bigger. The more intense cyclones are, the less chance buildings will remain in good conditions. We can't save everything – we can save part of it."*

Avatiu Breakwaters (2012) have experienced cyclone damage in 1987 and 2005 but the rubble and rock armour are reinforced, climateproofed to withstand up to 0.5m SLR and 12m wave height, to minimise exposure to gales, storms, cyclones and floods. However, it remains vulnerable to changes in currents and soil sedimentation affecting its foundations. Droughts and earthquakes /tsunamis are unlikely to permanently disrupt port activity. Landslides, Bushfires and Volcanoes are estimated to have no effect.

Table 5.12: Cook Islands Ports and Climate Change Risk-Vulnerability Exposure

Location	Port Assets	Risk Vulnerability	Resilience/Climateproofing
Rarotonga	Avarua/Avatiu above Aorangi Jetty	more resistant in wood than concrete	Above
Aitutaki	2 quays, 2 forklifts, storage shed/ equipment store 2 mobile cranes, 2 barges, stacking area	>2 metre depth, no sheltered anchorage, weak covered sheds, channel dredging	Coral reef, marine sanctuary, Raui conservation method, New breakwater, 22 m barge and 25T forklift
Mangaia	Channel, dock, boat ramp, storage shed, barge, dinghy	Reef exposed, sea level, swamps + lagoons -floods, more wooded, water supply/waste disposal	Each proposed new breakwater jetty, sheltered anchorage, port, cargo, crane and storage facilities, navigation aids, reef channel, 15 m wide boat ramp, bollards, 25 m quay strengthened, regular shipping service Raui, Reef, Vegetation. Caves –Mangaia/Mauke Need for reforestation
Atiu		No permanent staff/plans, facilities/port elevation, open fringe reef, overdevelopment, eco-pressure, limited port risk and stakeholder information/ awareness, static crane, volcanic soil sedimentation, outdated truck	
Mauke		Above flat plateau, partial breakwater	
Mitiaro		Above + 2 eel lakes/floodplain, >12 m height, obsolete equipment	
Palmerston		Above +Infertile reef/soil/land limit, electricity restriction, physical risk open areas	
Rakahanga		Above + infertile land, remote, shipping every 3 months, shallow reef flats, > 5m high,	
Nassau		Above + Overpopulation, lagoon proximity, few facilities	
Manihiki	Above + wharf/fuel storage	Above, lagoon + aquaculture risks maritime ecosystem	
Pukapuka		Above + solar cells failing, higher cyclone risk, narrow channel, beach sand –weak soil	
Penrhyn	Above +fuel storage, wharf, direct vessel access, dock area	Vessels access port directly, limited soil, deforestation, >4 m high, rainwater as water source	

Source: Author. Based on survey/interview estimates.

Port headquarters is only 400 metres from the wharf directly opposite the breakwater as a source of staff, information and communication and highly vulnerable to SLR, gales, storms and cyclones. It minimises response recovery time, with a siren in close proximity to most shipping and other stakeholders. With one maintenance and equipment workshop it remains exposed. Mobile assets (Table 5.11) depend upon storage conditions, maintenance/material properties and risk type mostly for cyclones, floods, rain, storm surges and wind. Open storage/container stacking areas are highly vulnerable to most risk types except landslides, with concrete surfaces, no coastal barriers, no supporting vegetation or trees as windbreaks. Vulnerability diminished from climateproofing the breakwater and relocating and strengthening sheds. Tsunamis and earthquakes remain under investigated or prioritised. As nations increasingly reject import substitution and localisation; favouring international trade, they become more susceptible to risk events, accelerating impact costs. Seaports affect imports, exports, transhipment, local cargo, passenger and migrant trade activity, which all stakeholders depend upon. Yet many nations remain ignorant on just how many ports, coastal communities and infrastructure will disappear within a few decades. Risk events also affect the extent of humanitarian aid efforts as well as pressurising existing supply chain activity when infrastructure, equipment, training and services are damaged/disrupted.

5.4.5: Risks to Shipping

Importers, exporters, producers and consumers are increasingly reliant on shipping companies, and governments on the revenue generated to survive. Yet, Pacific and other states fail to analyse implications if shipping risks proliferate. Although fluctuating with demand/supply, the Cook Islands hosts 5-7 regular shipping line callers per year, 20-40 cargo vessels excluding marginal, occasional callers, over 200 yachts and occasional cruise vessels (15 for 2017). There are 321 canoes, 593 non-motorised and 615 motorised boats with 2 fuel suppliers. Avatiu hosts 15-20 recreational and 25-50 fishing vessels on average. The Cook Islands Shipping Association, Yacht Squadron and Maritime Cook Islands shipping register were contacted to assess true exposure (Table 5.13). Shipping represented 6% of total respondents. A high risk-underestimation was affirmed, especially among international companies. Stakeholders were particularly ignorant of personal vulnerability, extent of resilience, business, country, regional and global risks. International shipping companies were reluctant to participate but neither they nor local could demonstrate awareness/adaptation from previous risk events. Climate change's prospective impact on flags of registry who lose their home port/inspection source, is ignored by international maritime law.

> "*We are regulators of ships. Issues impacting safety of ships and ports are of concern to us. Ocean acidification affects coral reefs and the impact of Rarotonga as a tourism destination and for food supply. Our organisation is unlikely to be directly affected by climate change. Our operating environment is likely to be impacted. We expect to be affected by a cyclone once every 10 years for a week. We are less vulnerable than before because our data and systems are hosted overseas and available through the Cloud."*

Without maritime transport; resources, cargoes, trade and humanitarian aid, not just maritime but general supply chains and economies would be severely impaired.

Table 5.13: Cook Islands Registered Shipping Fleet

Vessel type	Total	Gross Tonnage	SOLAS	SOLAS GRT	Classed	Classed GRT	Average Age
Barge	28	533,331.7			11	38,338	19
Bulk Carrier	18	687,381	18	687,381	18	687,381	23
Cargo	103	417,257.7	99	416,426	97	414,523	26
Fishing	16	8,518			1	3,960	33
Offshore	2	6,790	2	6,790	2	6,790	28
Passenger	5	2,679	5	2,679	2	1,898	27
Special Purpose	10	3,557.54	2	2,130	4	2640.47	33
Tanker	26	460,491	26	460,491	26	460,491	25
Traditional	5	204					10
Utility	49	19,566.1	7	8,817	31	15,735.6	28
Yachts –Commercial	45	8411.0	1	703	11	3,142.27	23
Yacht -Private	252				13	4,347.26	10
Total	559	1,685,892.8	160	1,585,417	216	1,639,246.6	18

Source: Author. Based on survey/interview estimates.

The most significant vulnerability exists not from highly aware domestic operators able to move mobile assets with sufficient information and communication warning, but for stakeholders and companies dependent on Rarotonga/Aitutaki's single fortnightly shipping service every 2 weeks for. Respondent 13 (Shipping operator):

> *"We do a lot of things for shipping and economies –hoping the vessels won't sink –some will not lose their lives. Hurricanes are coming too often, waves are getting bigger and ships are getting smaller, taking longer to bring the island closer. Costs are higher, people are fewer."*

Respondent 40/41: **"***We are aware of these risks expecting problems to develop. Rarotonga is in a really good geographic position from cyclone routes; getting around 5-6 days warning as it circulates down from the north. There is an issue of relocating for business but operators invariably ignore the risk and gamble. We prepare ourselves with shutters and move stuff up the hill. Basically, we are quite practised at it".*

The outer islands receive vessels only 1-3 months, even more vulnerable to shipping service disruptions throughout supply chains. Respondent 73 established reputational risks occur as non-registered or occasional callers divert trade from riskier destinations. Droughts affected water supply and increased fuel bunkerage damage. During risk events, performance and output productivity significantly decreased, delaying port throughput and export volumes.

Shipping stakeholders are more optimistically resilient and most take it seriously, living through several cyclones over recent decades. The Cook Islands are more adapted and prepared than many. The main problem is convincing cooperation when most changes appear only gradually. Respondent LXVII: "*Ship captains have noticed shifts in currents and far rougher seas."*

"Government has focused on risks and impacts quite well but it is not really maritime." Being mobile and footloose, vessels have greater potential to either divert course or if smaller, to be hauled up to more sheltered shore protection. Few sheltered harbours/anchorages exist for vessels: Avatiu and Aorangi Jetty (Rarotonga), Aitutaki and Penrhyn, with other vessels dependent on landings as coral reef gaps, exposed to beaches. Respondent XLI:

> "*We always worry the narrow harbour channel and entrance could be blocked. The outer sheds and heavy equipment upon which shipping depends could face major damage. The upgraded harbour and breakwater, however, are more climate resilient, lessening swells and wave impacts gradually. Perhaps smaller boats are protected more as they can find shelter. But it's probably not effective and quite vulnerable as harbour faces trade winds and eyes of cyclone."*

The Cook Islands Port Authority prohibits activity for winds exceeding 20 knots or waves beyond a certain height/energy. There are insufficient navigation lights, a single tug/pilot boat and 2 gangways, limited equipment and training. Crew and stevedores have increased risk. Ship cranes possess limited capacity. Outer islands offer limited infrastructure, no sheltered cargo/vessel storage capacity or permanent professional staff. Islands remain highly vulnerable, dependent on two scheduled shipping services visiting once every 2-3 months and with large distances between them. No updated hydrographic charts exist. All airstrips are 100-200 metres from the Pacific, at sea level with no vegetation or windbreak and permeable soil. Being exposed to sudden risks, they provide no aerial backup capacity. Limited land space exists for most islands, further indicating the significance of shipping mobility for trade. With no dry-docks, shipyards or marine equipment manufactories; shipping and supporting maritime infrastructure/equipment damage would experience significant risk recovery delays, importing from Fiji, Australia or New Zealand. There remains the unknown impact of future risks, feedback loops, emissions and Antarctic ice sheet melt/SLR.

5.4.6: Risks to Roads, Logistics, Storage and Distribution

4% of total respondents were from the logistics sector. These stakeholders include 5 freight companies, 11 shipping agents and 17 road transport companies, Ministries of Transport and Infrastructure/Planning, Cook Islands Trading Company and airfields/Airport Authority. Avarua and Aitutaki port authorities are highly interconnected and dependant on roads, bridges and transport with limited storage capacity and few regular shipping callers. Other MSC stakeholders are highly susceptible to cargo loading/offloading delays during events with only 2 stevedore companies. This is hindered by limited storage capacity of 3 vessels, restricted shipping services and relocating vessels/exposed assets during risk events. During these risk events, performance and output productivity significantly decreased, delaying port throughput and export volumes. Potential damage could impede risk response, recovery and adaptation.

Utilising existing localised sources including geophysical topographic maps (Figure 5.14), statistics, stakeholder consultation and field research observation can more effectively determine localised risk and vulnerable stakeholders. These confirmed 237 registered businesses and 7,108 potential stakeholders as producers, employees or consumers for Rarotonga. Over 81% are concentrated around the coast. These are within 0.5-1.5m of the ocean/potential flood source and less than 5m above sea level. Figures 5.12/13 similarly indicated the airport, seaport, fuel supply tanks and coastal roads are highly vulnerable, with limited reef protection and accessibility into the mountain hinterland (Figure 5.14). Only 2 main roads circulate the island using many low bridges. High precipitation levels, coastal erosion, sand mining and soil composition (predominantly stony/clay loam/underlying beach rock) and vegetation denuded/weak soil slopes indicate landside and soil erosion, damage potential. Whilst forest/vegetation protects certain assets, no mangroves exist. Wetlands and multiple streams indicate extreme vulnerability to floods, tsunamis, cyclones, storms and SLR for stakeholders up to 1km on an alluvial floodplain.

Climate change presents further risks to cargo operations, distribution and transfer affecting inspection, security, speed and quality. MSCs remain highly vulnerable with coastal roads exposed, no road quality standards, coordinated schedule/road master plan maintenance or upgrading policy existing. Respondent XLII mentions: "*I usually send a cyclone warning notice at beginning of season to certain stakeholders but didn't this year*". Existing traffic pressures, land constraints, limited enforcement capacity and high dependency on sand mining and coral materials for construction further increase ecosystem pressures and vulnerability to risk events such as coral reef acidification. Respondents 11/12 echo other factors. "*Very expensive fuel delivery, vast distances, low population numbers and high air freight costs. We need a subsidy*". 100km of sealed and 90 unsealed roads exist for Rarotonga. On outer islands roads are mostly unsealed of mud and crushed coral. Table 5.14 identifies specific impact consequences.

Figure 5.12: Key Cook Islands MSC Infrastructure

Customs, Port Authority

Power, Information, Communication

Market, Access Roads, Financial/Insurance

Source: Author.

Figure 5.13 Seaport, Shipping and Petroleum Infrastructure

Source: Author.

Table 5.14: Logistics Stage Risks

Climate Change Risk	**Impact Cost**	**Consequences**
Increased Temperature/Solar radiation	Bitumen embrittlement/cracking	Temporary/Permanent blocked road access
Increased Precipitation/Storms	Water seal loss causing potholes	MSC disruption costs
SLR	Submersion of low roads	Increased maintenance costs
Flooding	Submersion of low roads	Re-routing to avoid risk
Bushfires	Road foundation damage	Increased liability risk
Salinity/Ocean acidification	Coral bleaching/wreck	Higher Insurance costs

Source: Author. based on survey/interview estimates.

Logistics stakeholders primarily recognise transport as a significant contributor to climate change, focusing more on emissions mitigation than adaptation. The main stakeholder, also operating stevedoring/shipping, focuses on environmental sustainability. They primarily target imports and servicing tourism, hoping "*It's more sustainable, delivering the things you need such as employment. We can control the environment and land."* As climate change increases as a risk concern, logistics stakeholders worry about tourism's sustainability, lagoon nutrient loss, retaining vegetation and coastal erosion unbalancing the ecosystem, for effects could extend beyond their immediate supply chain. They question if business is always worth the opportunity cost. There is "*no clear-cut path as to how the Cook Islands will become more sustainable."*

The Ministry of Transport and government stakeholders echo concern about transport emissions, emphasising the need for data. They recognise a need for action even though they are susceptible without individual ministry policies for disaster risk resilience. Stakeholders are considering renewable energy, electric vehicles and other reduction strategies, even when government departments consist of only 4-5 staff. High awareness exists, but there is a predilection to perceive non-Pacific nations as solely to blame for increasing emissions and climate change. Respondent XXII "*It's not our fault – it's everybody's fault. Cook Islanders set a target by 2020 to 100% renewable energy. There is nothing much we can do except preparation – enforcing national convention/policy concerns".* Even the approach to calculate emissions is perceived as controversial. "*The Cook Islands does not agree with method asking: What's our contribution to emissions? We don't own any aircraft. It's not fair to pay the same!"* Stakeholders appear reluctant to prescribe compliance for all international and domestic contributors present; Respondent XXIII notes:

> "*It doesn't matter so much what we are doing here. It depends so much on what other countries do or fail to do. While our global emissions are small, we still are contributing. The last thing we want to do is nothing for emissions. One small country says 'It does not matter much' but 150 small countries say that, goodbye Kiribati…"*

Figure 5.14: Cook Islands, Rarotonga Topographical Map of Climate Change Vulnerabilities.

Land Information New Zealand (LINZ) 2016

Climate change is also echoed in climateproofing logistics infrastructure and stakeholder willingness to cooperate in adaptation (Chapter 7). Respondents XXXIII/XXXIV identify risks as "*considered in the design when it comes to finalising bridges and roads to accommodate sea surge of 0.5 metres and cyclones."* Government asset protectors are quite aware of past risk events as a recent government theme making stakeholders and departments more aware. Buildings are becoming more resilient and older properties upgraded to standards: However, there are challenges relocating schools and assets to higher grounds due to land ownership constraints:

> "*Most Crown Land is on coastal fringes – hilly inland with fewer options to relocate. We can only do so much to prepare and react reasonably given time and other pressures. A lot of things depend on people's actions and whether they feel we can stop/reduce/delay climate change's full impact."*

Respondent 50 identifies this awareness and cooperation among logistics, customs and other MSC participants, as a consistent theme registered by content analysis, dissuading the need for even more awareness programmes:

> "I *think everybody in SIDS is well aware of the impact after Kiribati and some of the low-lying islands. The issue is pretty much around with personal efforts and experiences by communities in the Pacific, very aware of what is driven by heads of states. We, Marshall Islands, Fiji, Kiribati are all pushing for greater awareness of climate change effects normal people see. However, many talk about climate change but we don't see actual data of SLR, personal risks or consequences. We just need accurate, measurable data to convince communities and larger developed states there is a realistic impact of climate change."*

5.4.7: Risks to Customs

The critical role of tourism in the national economy implies the importance of customs which is not exempted from climate change. The Cook Islands Customs Authority processes over 120,000 passengers and 60,000TEU's of cargo from 800-900 flights, 300 yachts, 50 cargo and 30 cruise vessels per year, 300-400 postal items and 600-800 air freight per month. It collects revenue from $28-$32,000,000 per year (34% of government budget). Supply chain stakeholders extend beyond the Oceania Customs Organisation region. Survey results found it to be an inconsequential facilitator/impeder of trade for global supply chains from producers to imports, exporters, retail, wholesalers, logistics and consumers. Climate change is not identified in its Public Sector Strategy and Business Plan for Customs 2013-2015, its training priorities, its resources and consultations of risk awareness.

Customs comprise 2% of targeted stakeholders. The Cook Islands have 9 designated customs entry points and 3 offices (Avarua, Aitutaki and Penrhyn), with 10 staff over 24 hours operation. All offices and storage/customs sheds and open stacking areas are physically vulnerable to cyclones, storms, floods, SLR and soil sedimentation loss, increased wind velocity, precipitation and temperature, impeding cargo. Changes in species migration and biodiversity, ocean acidification, salinity and droughts affect cargo quality/quantity, volumes and safety for physical goods inspections. Heatwaves erode productivity, decreasing Customs capacity to mitigate biosecurity and physical risks. During risk events, performance and output productivity significantly decreased, delaying port throughput and export volumes. Humanitarian aid limited cargo throughout which reduced resources to allocate to commerce and migration. The Cook Islands aim to process 98% of passengers within 1 hour is affected

Respondent IX, "*Climate change presents challenges threatening our responsibilities to preserve the national environment, safety and security. We must ensure we retain the capacity to satisfy business sector and individuals."* Customs provide a small window of 6 months, to speed and facilitate humanitarian aid goods to reallocate and prioritise resources reducing vulnerability. They perceive stakeholders as complacent at minimising emissions. Respondents were unable to provide information on factors influencing vulnerability and resilience, enhancing risks further domestically and globally. Inadequate training, information and coordination further increases customs' risk susceptibility, promoting congestion and delays to cargo, passengers, post and aid distribution during events. Local and international customs ignore these risks, lacking guidance on how they will affect stakeholder requirements and ignoring prioritisation of scarce institutional capacity and resources. This research evaluates Cook Islands customs as highly vulnerable to these risks impeding the clearance of passengers, craft; imports, exports, transhipments; revenue collection, surveillance, investigating offences, reporting, evaluation/audit inspection and protection against foreign competitiveness. Automated processing systems and bonded warehouses lacking redundancy are also vulnerable. Border security will be directly compromised from risks to health, trade, agriculture, fisheries and ecosystems. Transferring risk globally including secure transfer and information sharing, pressurises even less exposed customs administrations as future risks.

5.4.8: Risks to Import, Export and Transhipment

Whilst this stage proved the most unwilling to participate; providing limited evidence of actual risk concerns and high vulnerability, Cook Islands stakeholders include nine formal importers/exporters. Limited transhipment exists as a remoter Pacific port. Indirectly, risks influence all stakeholders for which localised goods are not produced/sold. 90% imports/exports are delivered via Rarotonga port and 10%

via Aitutaki. Table 5.1 and Chapter 6 summarise marine economy trade. Few stakeholders indicated specific risks. Respondent 97 indicated agriculture disruptions. "*Prolonged drought periods, changes in climatic and seasonal rainfall including shorter but heavier periods interrupt traditional agricultural cycles and the ability to store water for public distribution."* Respondent 69 expressed concerns importing outer island seafood. "*Droughts too because of tourism industry water demands and effects on agricultural productivity. Also there tend to be vector borne disease outbreaks such as Dengue, Chikungunya or Zika following droughts."*

Stakeholders were concerned about the accuracy of risk perceptions hen factoring in international trade. "*Again, this is subjective. We may think we are very aware but in reality there may be a lot out there, we are not aware of (Respondent IV)."* Risks influence and depend upon risks to producers, shipping, seaports, customs, transport, logistics storage and distribution, insurance sector, airfield alternatives, marketing, other domestic and international/competitor supply chains. The infrequency of shipping services to outer islands is paradoxically considered to enhance resilience by forcing more self-sufficiency, with Rarotonga and Aitutaki more import dependent, moving beyond subsistence agriculture and fisheries.

5.4.9: Risks to Wholesalers/Retailers

Cook Islands stakeholders include commercial enterprises directly and indirectly dependent on MSC resources. These include 4 wholesalers, individual shops, businesses and service providers (47 direct, 132 indirect), 3 shopping centres, 17 markets, 5 caterers, 102 cafes and restaurants and 84 accommodation providers. It includes local/foreign ownership and businesses abroad e.g. New Zealand/Australian pearl shops and restaurants from which supplies are purchased. 7% of respondents were retailers/wholesalers. In contrast to government, logistics and marine tourism operators, this stage affirmed the reluctance of many domestic retailers and wholesalers to directly cooperate and prioritise risk events. There was a high rejection rate with over 77 businesses not responding. Stakeholders cited:

> *"Thank you for sending your questions. I asked the Managers to look them over. Unfortunately, they don't feel they would have anything significant to provide for you. They don't have a significant amount of time to spare and don't feel they would be able add much to your research. Therefore, we will have to decline to participate in your interview request."*

Yet Cook Islands Trading Company was among the more climate exposed operators, the largest supermarket, building centre, bottle store, wholesaler, operator of fuel stations and logistics. It provides 67% of food imports in supermarkets outlets-by the coast with no generators, risks to refrigeration and limited fiscal reserves or redundancy. Businesses ignore risks, more concerned about daily operations, ignoring risks to resources with limited contingency planning for climate change. A jeweller cited **"***Our founder is currently out of the country until early December and will not be able or is interested to meet you."* A recently arrived marine tourism operator mentioned:

> "*We do not feel we are in the position to provide you with the quality of data you require for your research. We have quite honestly not yet had the time to better understand the local situation."*

Wholesalers are more vulnerable based on concentrated inventories, though simpler to invest in resilience. Most businesses are situated, 1km or less from the sea, consisting of thatch roofs, open stalls/wooden sheds for markets or flimsy buildings exposed to gales and cyclones. No alternative/formal arrangements for security or reliability exist. There are no town planning or building code restrictions to climateproof existing structures. The more distant the past event or location the greater the underestimation of perceived risk. Without any risk awareness consideration or co-ordinating partnerships (including information), vulnerability is increased. The commercial sector is more aware of general climate change's presence but not the details. Respondent I cited knowledge of where to locate more information, given regular government updates. It expressed concern business has not really considered climate change damage and needs to catch up very quickly, to promote resilience. Respondent 11 indicates challenges of conducting business with remote islands offering limited prospects. Around 3,000 people are distributed over 3,000 miles for these economies, which climate change will worsen. Several operators have gone bankrupt with over $500,000 debt. The commercial sector is trying to minimise risk exposure through diversification towards hydroponics and organic agriculture. Respondent XXIX notes climate change will create havoc for food supply, especially given existing labour/migration constraints.

Those willing to participate included one plumbing and water sanitation firm/community member concerned about climate change effects on the eastern picturesque Muri Lagoon. He expressed concern reef deterioration, acidification and species loss hindered his ability to teach his sons to swim, traditionally fish and conserve. "*We have to do something. How much we can do… how much we want do – that's the question."* As for future climate change: *"I don't see it improving in the future – but not sure whether can make any real change – except to slow the pace and drive the responsibility for impacts."* Respondent 57 indicated even greater risk exposure with fewer firms and more mergers from 3 major wholesalers/importers to 1. As foreign companies acquire local assets, they lack the historical experience that promotes more accurate risk awareness. She recognised how vulnerable supply chains are to a single point: "*Avatiu harbour is the hub. Without it, we are doomed."* Another wholesaler (Respondent XXVI) mentioned: *"Climate change with unpredictable weather patterns and SST to our marine resources,* *is the biggest income threat to our nation, countries and entire Pacific region given the disturbance to Nature."* Marine tourism operative representatives mentioned: *"There are a few naysayers, but most people are quite concerned"*.

Respondent XLVII indicated a degree of community and retail awareness but mentioned the problem of gradual effects appearing with adequate updated information. This challenged business aims. "*To provide quality fresh tropical cuisine using local ingredients in an enjoyable atmosphere and make a decent living to sustain us and our staff in the Cook Islands."* Retailers noticed declining species created uncertainty for supplies, although currently manageable. *"In* the *late 1990's boats arrived with 100tons yellowfin tuna or albacore, now 40-50 tons or less".* Others could not discern particular risks needing action. Respondent 64 indicated a concern to elevate assets from king tide surges. Respondent 67 identified heatwaves affect airconditioning capital and running costs, staff health and produce availability. "*El Nino/La Nina resulted in changed fish availability and thus affected business profits."*
Respondent 99 commented: "*Cyclones affects the whole supply chain for a period of time." "All of our properties are close to the sea."* Respondent 94 noted risks "i*mpact fishing properties and land-based activities".* "*Climate change is evident but comes in unpredictable scenarios, hard to anticipate which area to focus on."* Respondent 95 indicates why the Cook Islands are often so willing to embrace climate change, compared to others. "*We won't have a business if we don't have an island."* For many stakeholders, their awareness extends to personal experience and limited media coverage. The most significant risk to MSCs remains complacency. When local people have not experienced a cyclone since 2005/2010 and the majority of supply chain assets remain unprotected; any failure to adapt not just affects wholesalers and retailers but producers, consumers and the basis of marine tourism's future.

5.4.10: Risk to Fuel, Utilities and Interconnected Infrastructure

Cook Islands stakeholders include Infrastructure Cook Islands (water supply/waste/roads), Te Aponga Uira (electricity), the airport, Toa and Triad Petroleum. 7% of respondents were recruited from this MSC stage. All stages often operate under business as usual scenarios. Only when climate change presents cascading costs across supply chains, do many stakeholders register how interdependent these assets and stages are. Cyclones, storms and gales can paralyse essential goods and services far more, than other specific stage risks. Roads may be inactive for days. Fuel, water, electricity and telecommunications may be out for weeks, months or longer. Assets are primarily situated adjacent to exposed coastlines. Airport tanks lack storage capacity reserves inland, multiplying risks. ICI consider existing climateproofing has reduced cyclone risk vulnerability but this has been untested since 2010. The Cook Islands is pursuing 100% renewable energy by 2020 using photo-voltaic solar but Rarotonga is mostly diesel based.

Electricity peak demand is 4,400kW consuming 20,000L/day and 1 week storage capacity. Aitutaki has 5 obsolete generators. Electricity cables (underground or exposed), diesel generator backup sources and solar panels remain vulnerable to temperature, landslides, earthquakes, tsunamis, flooding, cyclones and storms. Central power stations are located by streams in flood zones. These remain vulnerable to fuel storage access -1,100,000l of diesel in above ground tanks, only 150,000l at the power station. Larger distances involve higher fuel dependency. Only Penrhyn of the outer islands possesses fuel storage.

The challenge remains for many *"whether to avoid it and let nature takes its course or take action."* Respondents 45/46, as electricity providers, perceive climate change as renewable energy and mitigation: While noting that their emissions are small, they feel they should reduce them:

> *We acknowledge we are a contributor, predominantly diesel carbon emissions. We are aware of the impacts and how they affect the island and as a result we have projects and programs in place to mitigate it. Information does help. The more you can get, the more you can achieve what you want to. We have undertaken a number of studies to achieve such an ambitious goal. We have just completed a report and in the process of determining what can be openly release into it. We have 2 main obvious choices solar and wind."*

Coastal substations need relocating as do roads. No protective mangroves/wetlands exist for coasts exposed to SLR, droughts, floods and cyclones. Water supply risks include ocean contamination, acidification, droughts and bushfires. It includes changes in soil sedimentation and composition. Most islands possess limited freshwater supply affecting aquaculture, bunkerage, producers and consumers, unless increased rainwater is harvested. Limited technical capacity exists with 2 maintenance and repair teams of 4 staff conducting sporadic repairs and 2 private plumbers on the mainland, indicating high vulnerability to climate change risks to water distribution infrastructure. Utilities and interconnected infrastructure lack natural vegetation and other environmental protection. Respondent LIII: "*I'm concerned tsunamis, storms surge and waves may shut business down leading to fuel contamination. The main risk is to the old pipeline, tanker imports and harbour/airport."* Private utility respondents were concerned about climate change with superficial awareness beyond areas expressed on mainstream and social media, lacking regular interaction and cooperation with government and other stakeholders.

The other 2 LPG and petroleum providers are even more vulnerable. Past storage capacity for 58 days fuel supply was damaged in 2005. The Airport remains vulnerable based on jet refuelling and northern runway edge's proximity to the ocean, SLR, storms and tsunamis. Gales also threaten its solar powered panels and operations, although it has not closed since operations commenced in 1974. Analysis indicated stakeholders currently have no incentives for adaptation and conservation given nominal electricity prices and free water. Rarotonga's water losses exceed 70% from old pipes, expanding potential drought pressures. Only 1-2 power stations exist per island. However, public stakeholders are targeting climateproofing between government departments to enhance infrastructure resilience. Since 2010, this has yet to be independently tested. Respondent 87: *"Tropical cyclones continue to damage Cook Islands. ICI is driving infrastructure in the whole Cook Islands. For it to succeed it needs to raise its profile and reputation in terms of addressing all of the above climate issues".* Respondent 89 confirmed that there has been collaboration around climate change studies, designs and implementations for some years. *"Climate change is a national priority. Our organisation's main role is climateproofing infrastructure roads, harbours, airport runways, buildings, water supply, sanitations etc. We also provide support to other sectors such as agriculture, environment and marine resources. In addition to the main responsibilities we are also involved in disaster risk management at a national and a community level. There is a very close correlation between climate change and disaster risk management. These infrastructure often fail during a cyclone event. Recent extreme rainfall events in 2014/2015 in Rarotonga caused flooding damage to roads, buildings and sanitation systems."*

Despite significant awareness and resource investment over climate change risks, stakeholders affirmed core utilities, infrastructure and dependent businesses continue to fail every time a direct hit strikes harbours, airports, roads, water and power. When the maintenance budget is not spent, it gets reallocated to lesser priorities.

5.4.11: Risk to Information/Communication

Accurate information and communication assist MSC trade and stakeholders; to identify risks, profits and opportunities, to recover from any disruption and to adapt. It coordinates individual stakeholders and entire systems, especially over large distances. Yet existing Cook Islands/other Pacific information and communications infrastructure and operations are highly vulnerable, which transmits further risk globally. Cook Islands sector stakeholders include Blue Sky Pacific (foreign owned), direct Internet satellite, submarine, telecommunication landline (7,700 users) and 11,000 mobile network users, postal services, 2 papers, 1 marine and 6 private land radio 1 national and 7 island community TV stations. Blue Sky Pacific are proposing a Moana submarine, fibre optic cable linking New Zealand, it and Samoa, whilst government have mentioned connections to Tui Samoa. Specific risks for information and communication include heatwaves and higher temperatures; wind velocity and gales affecting metal wires, fibre optic cables and worker productivity and physical vulnerability to events. Cables remain highly resilient to land risk events. Submarine cables, composed of glass, plastic, fibre optics and copper tubes are vulnerable to ocean acidification and increased SST, possible changes in species migration; increased sedimentation and soil erosion within proximity of a coast or changed currents, earthquakes and tsunamis.

Respondents for this stage represented 4% of the total. Climate change awareness is completely absent from the telecommunications industry locally and globally. They lack adaptive capacity, past risk experience and adaptation maintenance/resilience. This supply chain stage, which most individuals and businesses rely upon, remains highly vulnerable. Many stakeholders cooperate domestically during a risk event but not in preparation, mitigation or adaptation. Stakeholder content analysis further verifies how dependent supply chains remain on communications. Past coordination including the Cook Islands Media Association failed. No funding, media awareness or training, disaster communication plan, government channel or arrangements with private broadcasters exists for a risk event. Stakeholders remain ultimately reliant on commercially orientated print, radio, online and television media sources to relay risk awareness, increasing risk exposure. Much of Blue Sky Pacific's fibre optic Internet network and tele-communication infrastructure is vulnerable, as is its single emergency radio tower with inadequate 6 hour battery.

Respondent 7 notes that the ICT division does not focus on risks and policies but essentially on maintenance and basic government support on bringing the cable rather than supporting underlying coordinating infrastructure." They feel that the government neglects essential, proactive maintenance. *"So, by the time something fails, it ends up being very expensive, and the government won't have the funds to fix it up right then and there. People can go for months after the failure event without proper services, until some money does become available.* Respondent 91 expressed concern "*Any possibility there is an incident that could affect connections to international grid connections is of concern as all of our clients reside outside the Cook Islands."*

Respondent 71 considers tourism a great revenue source which needs roaming and IT access. They indicated buildings, radio and cellular towers, satellite antennas, underground cable networks and solar systems are disrupted whenever an event exists. "*Sea surges will affect infrastructure and services along coastal areas. High winds will affect towers and masts/satellite antennas. Flooding caused by rain can also affect underground services and buildings."* In contrast, Respondent VII asserted: that while they did not own any ICT assets.

> "*I have been involved with the Climate Change Unit here in various guises, working with the teams on projects, so I am aware of what they do to mitigate potential risks. The greatest areas of risk to populations if there was an incidence relating to a natural climatic event would be access to water, general food security and ensuring shelter (the basics of life and survival)."*

Internet remains slow, expensive, unreliable and capped pressurising systems during risk events, causing systematic outages from accelerated demand. One of the 2 media companies within a kilometre from the ocean and vulnerable to storms, gales, tsunamis and cyclones, initially appeared receptive to this research but was never available and non-responsive. Respondent IX (the other media company) emphasised willingness to propagate and broadcast awareness of climate change research/personal networking as an effective means of promoting research participation and communication. Whilst specific information/communication risks for media were neglected, he detailed active involvement with responsible government stakeholders during risk events and facing wave surges/king tides etc within hours of an event manifesting. He expressed willingness as a media operator to ensure further research exposure of this first study on climate change risks, impact costs and solutions for Pacific MSC's. He related how other studies focus only on direct damage to property ignoring hidden or sunk costs, economic, transactional and psychological costs of dependent inter-island communities.

Unlike other economies, the Cook Islands high risk awareness over climate change and natural disasters is assisted by frequent education, communication, information and other policies. Climate Change Cook Islands (CCCI) is directly under the Prime Minister's Office. The Meteorological Service and Emergency Management Cook Islands (EMCI) are similarly devoted, despite 10 and 2 staff respectively. However, EMCI founded in 2005 lack detailed historic risk information of major events as foreign consultants never transferred records. Previously only cyclones were considered with 2007 legislation focussed on all disasters replacing the 1973 Hurricane Safety Act. The concept of disaster risk management and climate change is fairly new, only emerging as a priority or concern in the past 10 years. These stakeholders' express challenges of moving from just reaction and mitigation to actual adaptation and proactive preparation, given gradual risk changes. However, they stated people like to see what they can do to reverse the impact and what the impact is. Respondent 81: "*People do like to see things change.*"

In 1889 Rarotonga rainfall records started; temperature and other data since 1922. Outer Islands only started after 1997's Cyclone Martin. Respondent 52 mentioned the aim is: *"To ensure the safety of clients as much as reasonably possible by risk monitoring aviation, tourism and other sources of wealth for the Cook Islands people". "We also encourage people like yourself to contribute to a safe planet and people's welfare and are clearly well aware of climate change risks".* They signed various conventions, part of IGPCC to encourage people to act. A 36 hour alert is issued for all cyclones and full formation using satellites, if gale force winds exceed 35 knots/47kph. They are monitored during their average 3-5 day lifespan and observed 15-30 days beyond. Consistently stakeholders have benefitted from over 3 decades of experience and efforts from information and communication. With a projected increase in category 4/5 cyclone events in the future, people will have to become even more innovative in their resilience. Direction could focus on less experienced private sector, communities and foreign individuals. Respondent 37 proclaims: "*People's and species' lives should be nothing to compromise on in the future".* All interdependent stages need to ensure safety, security and welfare not just from past disaster events or immediately post-disaster but throughout recovery and opportunity.

5.4.12: Risks to Marine Tourism, Marketing and Administration

This MSC stage extends to marine tourism operators, publicity agencies and government authorities, not classified by the above categories. 21% of total interviewed and survey stakeholders presented the most significant stakeholder category. All vulnerable stakeholders experience risks to administration and reputational risks involving potential marketing. Only 3 private sector marketing firms exist but media, Cook Islands Tourism Authority, Pearl Authority and Investment Corporation are affected by climate change risks. However, previous research relating to climate change frequently ignores stakeholders in this sector. Numerous Pacific marine tourism operators and marketers continue to prioritise business. Large firms, dominated by expatriates ignore local risks, capacity and experience, augmenting costs to domestic assets and operations. Inexperienced stakeholders, especially smaller ones possess limited awareness and resources to resolve this. Marketing firms and government agencies have not incorporated this sector to the same extent as producers, aquaculture, utilities and communities. Impacts exist on liability, future sales and investment revenue, supply and demand. Existing climateproofing efforts ignore publicity and administrative connectors. If these were impaired, miscommunication could significantly enhance vulnerability.

The most significant role for marine related administration is reacting to minimise immediate risk and vulnerability, recovering to business as usual and adapt. Neither international firms nor media etc considered how climate change not only affects physical supply chain's economic activity but also psychologically – reliability/other requirements of dependents. Existing marketing arrangements are /short-term rather than established relationships. Stakeholder content analysis indicated factors influencing vulnerability including firm size, number of firms, experience, resources and capacity to access information/communication. Without accurate time series risk identification, awareness of past experience, information, communication and coordination, many lacked resilience. Others were less willing to participate. "*Thank you for your enquiry but I regret to advise our responsibilities have no relationship to your field of study".* Respondent 69 highlighted 5 cyclones in 2005, Cyclone Pat (2010), other storms and cyclone warnings, 1998 El Nino drought, 2009 and 2015, trifecta vector borne diseases and various fish shortages/price hikes including February 2016 as specific risk examples with adverse publicity and demand for marine tourism and marketing operators. Some operations took 2-3 days to recover, others up to 12 months. They could not determine their own assets and businesses' vulnerability: "*This is the big unknown." "Hard to answer*." Respondent 70 expressed: "*We do worry about slow onset impacts, not just catastrophic events."* Respondent 72 articulated telecommunication concerns: "*The tourism industry is a main revenue source for our organisation. Damages to our infrastructure and the country's ports due to adverse climate conditions will greatly affect our business."*

Many expressed awareness and concern for marine environment risks. Respondent 98 (dive operator) emphasised "*The main priorities for my business are healthy coral reefs and abundant reef fish life."* There was concern for "*damage to the reefs decline in tourism once the island gets badly hit."* Respondents 5/6 emphasise the need for ensuring marine resources can be safeguarded for sustainable tourism goals. *'Islands are affected by king tides, saltwater inundation and increased drought'.* A perceived lack of credible international leadership and action, such as the US President, climate change sceptics and visible effects have increased interest in discovering individual nation, proactive approaches. Several respondents considered it hopeless or inevitable. Respondent 29 integrated wind and sea surge into design and operations –imagining what is going to happen. They identified more stonefish, hundreds of mud crabs and other invasive species. "*The problem is just nothing changes rapidly so you can visualise it and be horrified; prompted to act."* However, as lagoon conditions deteriorated, tourism operators and the community are prioritising a joint response to risks. The government was unconvinced, prodding for excess bureaucratic barriers rather than action, ignoring visual displays including coral smothered by algae.

Tourism operators note that tourism contributes around 60% of the economy. As described by their voices: *"All our eggs are in one basket. Government takes limited steps to try and diversify the economy. The problem we have is we are running out of time. I suspect we are still vulnerable each November-April cyclone season. The tourism industry would be supportive to any research and adaptation initiatives but at the end of the day realise we will look after ourselves".* They were concerned about climate change sceptics, but commented. *"Extreme events mean they can credibly say this no longer. Externally we do not know what will happen and the global response. All we can do is see what is happening elsewhere concerning climate change and learn from it."*

They noted that a lot of aid money comes from Australia, New Zealand and EEU and that authorities tend to be guided by its use. Being less aid dependent was seen as an advantage. (Respondent XXV)*:*

> *"Left to our own devices; we probably advocate a more extreme position over climate change. Most of our tourism industry is vulnerable on the coast with extensive capital investment. For adaptation –what*

can be done, what should be done, what are the limits and constraints? The presumption is the problem is there. It's not going to go away and any countermeasure that we take to adapt will only be partially effective. It's going to be really necessary to adapt, otherwise businesses will not survive. Hopefully given support/aid funding, communities are more likely to endure. As businesses we have to be realistic by cutting down costs."

For MSCs to effectively climateproof, far more marine tourism operators need to be conscious of threats to their physical environment, assets and ecosystem resources rather than expecting government action or relying on insurance. "*Fundamentally the business community focuses on ticking boxes rather than ensuring resilience; reducing vulnerability rather than the way forward" (*Respondent XXXIX). They need to consider how prosperity will be retained rather than complacently assuming it is not their long-term problem. There appears little evidence of mutual cooperation and information sharing with Pacific tourism operators viewing each other as competitors, rather than curtailing existing ecological pressures, pursuing eco-tourism and communicating to pool resources during risk events. Marketing approaches need to register their roles in promoting environmentally conscious actions upon tourism, logistics sector, producers and retailers. Chapter 6 emphasises how operators struggled to recover from adverse publicity from previous risk events. Respondent 78 was concerned about over-complacency, particularly over-reliance on risk assessments: *"I.e. I won't be around so it is not my problem. This isn't true. I don't think risk assessments are rigorous enough. There is the problem of not forecasting for long term projections. A risk assessment is a continuous ongoing process. The risks will be different next year. Of course, we know what the main problems are but being gradual, but we really don't see it."*

Stakeholder inaction threatens most imports, pearl exports and employment sources throughout the supply chain, even ports, customs and utilities revenue indirectly. In contrast to administration/government, tourism's biggest concerns are more immediate. But in reality, they could be stricken at any time, as with Cyclone Geta's 5m wave surge in 2018. Operators were concerned that climate change as a problem may already have passed the tipping point. They recognised that a response was necessary in order to preserve their businesses. Respondent 45: *We would experience a downturn in tourism numbers as among the first to directly encounter global climate change locally, e.g. the European market. For New Zealand there is less of an impact because there is likely to be more affinity there. Australia is a bit more remote and are not likely to aid us with other problems."*

5.4.13: Risks to Consumers

When maritime and other supply chain resources, systems, infrastructure, assets, technology, communications and trade fail, consumers experience significant risks. Previous research marginalises this vulnerability. Cook Islands has a population of 17,794 but 14,974 actually resident. Only 6 (6% of sample respondents) answered highlighting the significant challenges of researchers to validate climate change, risk perceptions and concerns across an entire MSC; even in South Pacific nations with frequent events. It re-emphasises the significance of pursuing adaptation among stakeholders reluctant to participate and prioritise climate change action effectively, rather than relying on governments. With 37 incomplete, unusable responses, a significant statistical discrepancy arises between stakeholders proclaiming they are well aware of projected risks but uninterested in spending more than an average 2 minutes 23 seconds on it. They offered no specific details over risks, impact costs or solutions. Stakeholders demonstrated limited awareness of how specific risks would affect supply chains, economies and personally, as consumers, employees or employers. As Table 5.3 summarises, several events can occur simultaneously multiplying risks. Even usable responses had a typically sparse comment, "*Cyclone 2007 damaged property, unsure about risks and vulnerability,"* (Respondent 90).

Content analysis noted community representatives emphasising physical observations as motivators why Cook Island consumers recognise climate change hazards to MSCs. They notice "*Trees once on dry land are now in the sea," "loss of 2-3 metres of coastline, saline intrusion on water tables and manioc, vegetation loss, fish that have not been seen in 50 years."* They recall extreme droughts and cyclone events, especially in 1997, 2005 and 2010. As traditional agriculture is encroached by marine tourism operators and agricultural productivity/viability diminishes, marine resources and their potential for export revenue become more significant. revenue become more significant. Respondent 95 mentions *"Food crops affected by lack of water catchments for droughts and the need for relocation of households and crops due to sea level rise and saline intrusion."* Any supply chain disruptions to financial services, producers, consumers and subsequent stages are magnified from volatile events, lower food security and greater imports.

> "*Private and government homes, power supplies, telecommunications, wells in the outer islands were contaminated, water spouts damaged, taro an important part of the economy was spoiled with seawater, local schools and the areas around it, with asbestos, medical supplies and the people during cyclones and droughts."*

Unusually, local administration (Respondent 50) did not seek more information: "*I don't need any more. We have run these causes and issues again and again because we have been running this issue across* *the outer islands, conducting various workshops and training for stakeholders to understand this."* Respondent 58 echoed this being involved in producing crops to promote resilience in the community. He agreed that there had been awareness and training, but felt they needed to see clear, visible examples:

"They know of cyclones and frequent dropping water levels clearly linked to climate change. They have been requesting water tanks from government, to improve resilience with their resources". "There were other areas where the community needed help but these were the most urgent and pressing nneeds that the community frequently raised."

Frequent events over a long-time period proved the most effective forms of risk awareness with consumers and communities willingly participating. Respondent 58 perceived the need to more accurately link cause with risk and impact to provide scientific evidence, further convincing any reluctant individuals and businesses:

"The only major difference to climate fluctuations is in the past people did not talk of climate change. You see some changes but scientists ask for data -too poor datawise and equipment-wise to convince others it is happening. It's very difficult to collect data. We talk about digitalisation but we don't really have that."

Respondent 59 represented multiple community roles, often offering divergent perspectives based on respective positions. She alluded to noticing king tides, elevating assets; changing currents and lagoon issues with erosion. People visibly living with the changes are perceived as well aware; even when lacking the resources or will to respond. They know of the catastrophe's existence but not the extent of the impact and response. Outer islands have limited prospects for income diversification and resource security. Despite climate change and migration, many stakeholders perceive the Cook Islands as home, aware of needing to monitor and adapt to risks. They appreciate each atoll's significance to an economy/country and how climate change affects sovereign identity, far more than merely each stage or the complete MSC. She mentioned ecosystem values as effective resilience. The coconut is the 'tree of life', especially when droughts make fresh water scarce. Indigenous knowledge provided another recurrent theme (Chapter 7) accounted as a means of learning effective responses.

Stakeholders were unable to ascertain true personal resilience/vulnerability/risk; lacking access to current/historic risk information. They could not identify many of the threats to their economy and resources and did not know how to source relevant material with finite time/attention span for priorities or considering risk too low/distant. While the Outer Islands may be more vulnerable with fewer retail/storage/infrastructure options, but less frequent transport/cargo services partially enforce resilience.

Aside from uncertain psychological reactions, a significant barrier remains in unwillingness to accept personal responsibility. Stakeholders should consider how each's involvement or inertia is influenced by or influences others. For other supply chain stages, it is insufficient to invest in climateproofing while ignoring key consumers, employees, taxpayers, and disruptions to livelihoods, consumption, survival and income.

5.4.14: Risks to the Financial/Insurance Sector

Existing climate change research insufficiently estimates underlying systematic risk exposure of various supply chain stakeholders and stages to the financial/insurance sector. Business, consumer, producer and general recovery depends on credit extension and insurance provision against risks. Stakeholders include ANZ, Bank of Cook Islands (11), Bank of South Pacific, Westpac, Capital Security Bank, 9 insurance companies, 1 money exchange, Cook Islands Trust Corporation and the Financial Supervisory Commission representing domestic and unknown international customers. These experience similar physical risks with all branches/ATMs situated within 1km of ocean at sea level and proximity to other risk events, (except landslides). Despite its significance in providing credit, savings, investment and medium of exchange/protection against risks, the Cook Islands financial sector remains completely risk exposed. A mere 4% of respondents offered their perspective. All businesses were physically vulnerable, assuming brick and glass branches survived flooding, cyclones, wind gusts, storm surge and wave energy. No respondent was able to identify climate change risks covered in survey questions recall experience of past risk events, mention specific training or contingency reserves. When asked none considered plans, record backups, consultation and coordination with key stakeholders, alternative cash deliveries or adaptation/recovery considerations. This ignored existing experience disrupting cashflows between savings/deposits and investments, credit and loans. Nor could they identify potential risks to customers or other stages.

Storms/Cyclones have disrupted telecommunication systems, currency reserves, electricity/ATM technology and security. They have experienced satellite disruption from cyclones and physical cash despatched to Aitutaki, ATM's (water damage) and impacts to lending, underwriting mortgages and taking ownership of risks. All public assets under $50,000 are ignored by the Cook Islands Trust Corporation including vehicles, computers, port equipment and buildings. 80% of registered tourism operators have property/business interruption insurance but most exempt cyclones (the highest probability risk event). High premiums, lack of competitors/reduced incomes exclude many key producer, aquaculture, retail and consumers. Reinsurance presents higher premiums. During risk events, the financial sector would collapse with no indication of responding to a single, (let alone multiple), risk event. The insurance sector would require greater cash outflows to compensate policies; given the highly vulnerable number of affected stakeholders. Banks need to provide customers with access to fund relocation, recovery and adaptation costs. However, few qualified staff exist with limited reserves and local capacity and without information. Formal criteria for ascertaining asset risk/resilience, vulnerability and value/information on true risk were lacking in local branches and international Australia/New Zealand headquarters. Certain policies restrict liable payments for risk events to limit banking sector exposure but increase risk exposure of multiple defaulting customers/producers.

Respondents III/IV revealed the Cook Islands does not operate currency control, fiscal or monetary policy. They focus more on credit, operating, liquidity, capital risks, anti-money laundering and terrorism risks. No efforts were involved in facilitating climate change risk awareness or efforts to alter operations, despite impact costs. Respondent XLIII/XLIV indicate banks provide clients *"with credit, telegraphic services and international/local business assistance; act as an agent to support government yet separate commercial entity, registry of motor vehicles."* They aided with renewable energy credit rather than focusing on offering forms of disaster insurance or adaptation. Insufficient information to accurately ascertain risk exposure from businesses and individuals exists. However, the 4 respondents indicated willingness and risk concern. Respondent 67: "*Physical climate change consequences of could cause significant impacts to the operations of financial service providers in the Cook Islands via closure of businesses for cyclone warnings and the event themselves. This typically happens at least once per cyclone seasons."*

However, the sector still remains mitigation obsessed; ignoring fundamental systematic risk from simultaneous collapsing of ecosystems, economies, supply chains and loss of customers. Risks threaten bank physical infrastructure, ATMs, staff assets and reserve requirements. The Cook Islands 2011 Banking Act requires a physical presence and operations, capacity to avoid hindering trade, protect consumers/restore business. Climateproofing credit, is not offered ignoring small businesses, assets, systems and risks. Foreign aid/loans have concentrated on public asset risk protection given risk averse/unconcerned private sector. It excluded significant individuals/businesses upon which institutions depend upon for loans, deposits, solvency and liquidity. Remittances and aid are challenged with physical branch and ATM loss and electronic/telecommunication systems failures. Flooding/wind speeds and higher temperatures may affect operations, audits, records and reserves. When banks, remittances and insurance fail, few consider the size of existing cash reserves and how long supply chains will survive. With climate change, perhaps no limit exists to risks and disruption.

5.4.15: Risk to Entire Pacific MSCs/Other MSCs

Singular, accumulated and joint risks both internal and external; threaten not just single stakeholders but all those within each stage. They pose direct and indirect risks to an entire Pacific MSC system. As detailed in Table 5.2 changes to ecosystems threaten environmental resilience capacity and future resource security, upon which commercial activity occurs. Event frequency affects human psychological capacity. Increasing globalisation transfers risks, enlarging exposure, simultaneously not just to the Cook Islands entire MSC, but other interdependent global MSCs. Physical infrastructure, psychological, reputational, legal and other risks accelerate.

Systematic supply chain risks from climate change can be categorised as Physical, (Human) Psychological/Reputational, Financial, Infrastructure, Assets, Ecosystem, Resources, Information and Technology, along with other adaptation constraints. These produce impact cost consequences other nations could learn from. The extent to which climateproofing is effective is determinable only by antifragility. Certain events including cyclones, tsunamis, storms and droughts have far greater costs than others. Multiple systematic risks affect operations, increasing conditional probability of overall systems failure beyond individual risk. Analysis investigates the significance of each individuals' decision to prioritise action. From marine ecological conservation in traditional reserves providing sustainable pearls and fishing, to attracting marine tourists, which retains imports and exports, aiding utilities revenue, logistics and shipping companies to the port; prioritising climate resilience aids entire supply chain stages and systems. All users benefit from experienced risks and managing risk perceptions to convince action.

90% of international trade is carried by ships. Whilst the Cook Islands may be able to withstand certain specific risk events, through climateproofing key infrastructure existing risk management methods, still ignore other key sectors/risks. Risks are no longer once off individual events as conventional theory/research infers. Respondents demonstrated challenges in identifying stage and system-definite risks during the surveys. A climate change framework enables stakeholders to identify stage and system-definite risks. This creates a prototype for Pacific, global and land supply chain equivalents determining how much risk is acceptable It also illuminates when resilience has failed/succeeded and the extent to which maladaptation exists. Ignoring these risks, not only enhances individual risk but vulnerability of the entire MSC. Stakeholders will no longer be able to restrict vulnerability to a single, specific risk, commodity, stakeholder or supply chain. From survey-captured information, stakeholders only target physical, not ecological, psychological, systematic or accumulated risk.

5.5 CLIMATE CHANGE RISK PRIORITISATION FOR THE ENTIRE COOK ISLANDS PACIFIC MSC:

This section presents climate change risks facing the entire Cook Islands maritime supply chain. Given the views and concerns expressed by survey and interview participants about climate change events and impacts, the following criteria can be used to prioritise climate change risks.

- Probability of an Event, then Asset Failure/Urgency
- Frequency
- Rarity –Ecological Sustainability
- Impact Cost Magnitude/Duration
- Vulnerability/ Resilience
- Revenue Earning Capacity/Functional Significance and Asset Interdependency (utilities, roads, port, transport, bridges, communication/information/disaster risk management
- Time/Recovery Time
- Constraints to Adaptation
- Adaptive Capacity
- Resources Available

Based on the selection criteria presented above, this thesis proposes previously identified risks are prioritised for Pacific stakeholders including the Cook Islands and MSCs. The Islands have more time to adapt human, natural, technology, infrastructure, equipment, information, communication, system and other assets to long-term, scenario risks (Chapter 4). However, emissions mitigation must be prioritised immediately to ensure supply chain and physical survival. Stakeholders can prioritise various short-term risks, by referring to their respective frequency presented in.15. This illustrates cyclones represent the highest, existing proportion of recorded risks (33%), followed by storms (27%); unlike non-occurring bushfires, earthquakes and volcanoes. Currently 88% of stakeholders perceive drought as their foremost risk concern, contrasting severely with a mere 2% of historic occurrences. This is due to a drought in 2015, which is a recent memory. For low probability, high impact risk events, this section advocates initially measuring event increases from historic data, combined with climate change scenarios, (adjusted for an increased frequency, duration and intensity). This counteracts stakeholder uncertainty, as new risk types are considered highly unlikely by this thesis to emerge. Stakeholders then consciously ensure they know how risks threaten individual operations, underlying ecosystem and entire supply chains.

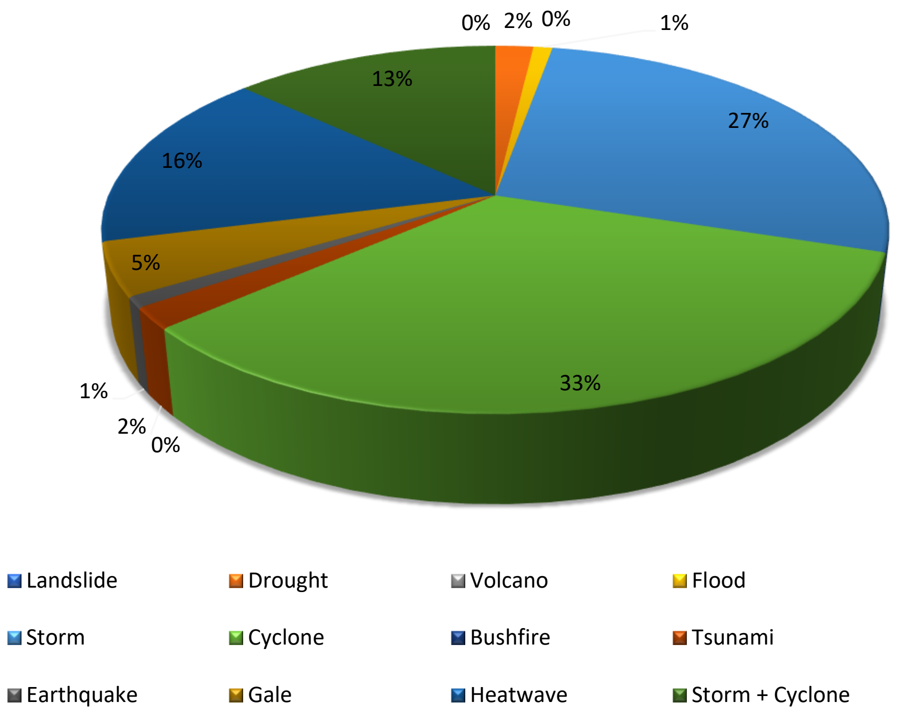
The most historically frequent, Pacific, climate change events from 1900-2015 are summarised in Appendix IX, for MSC stakeholders to ascertain risks. The advantages of gauging historic and future risk through probabilities, tables and pie charts emphasises the uniqueness of location specific risks affecting localised impact costs. Previous research primarily treats risks as equally likely to increase for all areas; as does conventional risk management for supply chains. For example, where Cook Islands stakeholders consider heatwaves and cyclones as most significant and urgent, Nauru's equatorial position and stable climate, favour only droughts and floods (Figure 5.16). This research utilises existing risk-related disasters to calculate expected probabilities of future risk events occurring. These depend on the risk type, MSC stage and geographical location, rather than previous climate change, impact studies merely identifying a projected increase in severity, intensity and frequency for all risk types.

Table 5.15: Prioritising Cook Islands Climate Change Risks for Pacific MSCs

Cook Islands Risk Event Type as Percentage of Total Risk 1900-2015		
Risk Type	**Frequency Total**	**% of Total (n =107)**
Landslide	0	0
Drought	2	1.87
Volcano	0	0
Flood	1	0.93
Storm	29	27.10
Cyclone	36	33.64
Bushfire	0	0
Tsunami	2	1.87
Earthquake	1	0
Gale	5	4.67
Heatwave	17	15.89
Storm + Cyclone	14	13.08

Source: Author

Figure 5.15: Prioritising Cook Islands Climate Change Risks for Pacific MSCs



Source: Author.

Table 5.16: Nauru Risk Event Type as Percentage of Total Risk 1900-2015

Risk Type	Frequency Total	% of Total. n =31
Landslide	0	0
Drought	27	87.10
Volcano	0	0
Flood	4	12.90
Storm	0	0
Cyclone	0	0
Bushfire	0	0
Tsunami	0	0
Earthquake	0	0
Gale	0	0
Heatwave	0	0
Storm + Cyclone	0	0

Source: Author

5.6. SUMMARY:

In conclusion this chapter addressed KRQA. This establishes how aware, resilient and vulnerable Pacific, MSC systems, stages and stakeholders are to climate change risk events through a Cook Islands case study. Key findings indicated:

- From 1980-1999, average Cook Islands SST was 26.5º. Coral with maximum temperatures of 25-29º have resilience limits, which collapse, as with other maritime ecosystems.
- Increased SLR, wind velocity, wave energy, reduced surface runoff during El Nino/droughts, river flow, changes to oceanic currents, freshwater, lagoons and soil sediment provide future risks to maritime resources and interdependent supply chains. Although human population has declined from 21,000 to 15,000 (1990-2016), tourism is increasingly unsustainable.
- The need to distinguish between physical and psychological, adaptive capacity when prioritising risk. While analysis found cyclones and gales to be the most frequent events, prioritisation of risks by stakeholders was influenced by the most recent events e.g. droughts, rather than actual occurrences over time.
- Stakeholder awareness of climate change and impact on ecosystems varied across MSC stages. Awareness was high amongst tourism, government and local resource-dependant stakeholders, but far lower amongst consumers, foreign retailers and importers/exporters. As content analysis affirms, numerous businesses, especially producer, consumer and financial/insurance system stakeholders, remain unaware of specific risks and vulnerabilities for supply chains. This particularly applied to those with head offices outside the Cook Islands. Customs services is a previously unidentified vulnerable stage.

- Providing data of actual events and probabilities will therefore produce more accurate risk perceptions and estimation to plan and allocate resources. For low probability, high impact risk events, this method advocates initially measuring event increases from historic data, combined with climate change scenarios, (adjusted for an increased frequency, duration and intensity). The advantages of gauging historic and future risk through probabilities and this grounded theory approach utilising psychological risk perceptions; counteracts stakeholder uncertainty, as new risk types are considered highly unlikely by this thesis to emerge. Existing infrastructure is recognised to as highly vulnerable with limited maintenance, fiscal and other constraints, primarily situated around the coast/floodplains.
- It identified the extent of supply chain individual, stage and systematic vulnerability to various risk events. This was affirmed via figures, projections, and qualitative content analysis from contacting stakeholders.
- Though vulnerable, certain Pacific stakeholders appear more psychologically prepared for risks based on existing natural disaster events, given limited physical capacity. They learned from experience not to underestimate risk but to prioritise. This aims to rectify the research gap of developed world ports, supply chains and stakeholders' case studies, which fail to recognise and prioritise this emergent crisis. They could learn from the Pacific and existing risks to consider an uncertain future.

The Cook Islands MSC remains highly vulnerable to risk events, in ignoring risks to resources and ecosystems. This is despite previous research and climateproofing adaptation strategies implemented. It and other Pacific countries/regions prove empirically, the results of climate change risk uncertainty for stakeholders, when risk extends beyond individual operations to collapse entire maritime ecosystems, supply chains and systems. With globalisation, any stakeholder connected to the Cook Islands, becomes vulnerable, although ignorant of localised risks. These results illuminate consequences of continuous risk underestimation from stakeholder perceptions; neglecting existing experience as a prototype for worse future conditions. Selective climateproofing of state infrastructure when pursued is often insufficient, inefficient and misdirected to reduce risk occurrence, the extent of risks and increase adaptation. From the Cook Islands and Pacific, to the world risks ignored, flourish.

CHAPTER 6 RESULTS: QUANTIFYING TRUE IMPACT COSTS OF CLIMATE CHANGE: THE MARITIME SUPPLY CHAIN OF THE COOK ISLANDS

6.1: INTRODUCTION:

To answer Key Research Question B, this chapter aims to identify projected climate change impact costs for a Pacific MSC system. KRQB enquired: "What are the economic impacts of climate change disruption risks on the future of Pacific MSCs?" This thesis consults participants to determine impact costs to individual stakeholders and stages. This aims to aid them to understand accurately the personal risk consequences, not just those to entire economies, ecosystems and supply chains. It seeks to incentivise risk action as soon as possible, via proposed specific strategies in Chapter 7. It enables participants to consider possible partner and competitors' costs, given commercially sensitive data, limited information and other adaptation constraints and adjust trade accordingly.

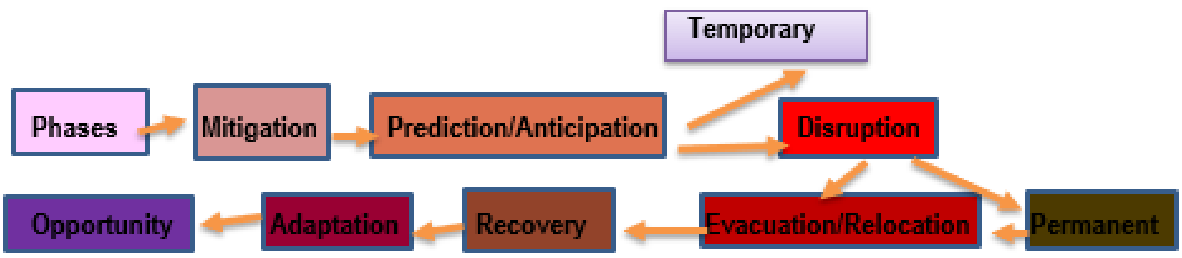
Section 6.2 identifies further research gaps of existing impact cost/cost benefit analysis for stakeholders. It outlines thesis method advantages in specifically valuing Pacific MSC direct, indirect and intangible costs (including ecosystems), to assess risk and stakeholder perceptions of impacts. 6.3 summarises a Pacific MSC/economy overview. It offers a Cook Islands case study. Section 6.4.1 provides field research survey and data results. It analyses projected impact costs across the entire Pacific MSC system, for stages and stakeholders, through a specific 2005/2010 cyclone risk event. 6.4.2 identifies specific research factors that affect impact cost magnitudes and contribute to recovery and resilience success or failure for stakeholders. 6.5 summarises the results' significance. It analyses implications for researchers, policymakers and stakeholders, especially in aiding adaptation in Chapter 7. It outlines how cost estimates can potentially diverge under climate change scenarios, time horizons and risk types. This considers how localised costs can rapidly increase to the Pacific region and global supply chains; further requiring world, climate change action and cooperation in commercial adaptation.

6.2: DETERMINING DIRECT, INDIRECT AND MARITIME ECOSYSTEM RESOURCE COSTS FROM CLIMATE CHANGE RISKS

To further evaluate climate change risks facing Cook Islands stakeholders; this section proposes revaluing Pacific and other MSCs. If stakeholders aim to avoid maladaptation, minimise disruption, survive and prosper, it is necessary to understand consequences. This determines where to allocate resources amid conflicting priorities to respond most optimally, learning from experience to improve adaptation. Conventional cost-benefit and impact cost analysis considering future risk events calculates effects after an event has occurred. Stakeholders may experience time lags in understanding how expensive inaction, delays or maladaptation can be. A proposed bottom-up approach through specific questions aims to improve existing impact cost estimates/methods, especially through incorporating direct, indirect and intangible ecosystem costs.

This chapter covers climate change impacts that tend to be overlooked in previous studies such as loss of entrepreneurship, investment by local and foreign key stakeholders, their direct, indirect and intangible cost. The impact costs are specified in Appendix V's questionnaire based on Figure 3.2's risk event, contribution tree and analysis. It estimates impact costs for a risk event. Empirical data enables stakeholders to test hypotheses and monitor the effectiveness of existing strategies, aiding risk-based decision analysis and effective resource/risk management. It considers what magnitude of impact cost is sufficient for stakeholders to react or encourage adaptation. Its advantage specifically concentrates on why certain stakeholders succeed or fail, and how much adaptation is truly necessary to reduce projected impacts, ensuring recovery, resilience and opportunity. Figure 6.1 proposes that future impact cost analysis could distinguish between impacts at different phases. Considering standardised data collection approaches to manage current and future risk impacts aims to optimise adaptation strategies, to minimise disruption and preserve stakeholder requirements. A lack of historic impact cost data is overcome by directly assessing stakeholders/secondary data/other techniques to ensure sufficient information is provided. This aims to rectify promptly disruption or impact costs to minimise loss and damage, including shadow/nonmarket cost approximations where market values cannot be obtained. Limiting time horizons provided to 1, 5 and 10 years overcomes the problem of year-by-year data when data format can be event specific and limited.

Figure 6.1: Risk Event Disruption, Impact Cost Phases for a Pacific MSC



Source: Author.

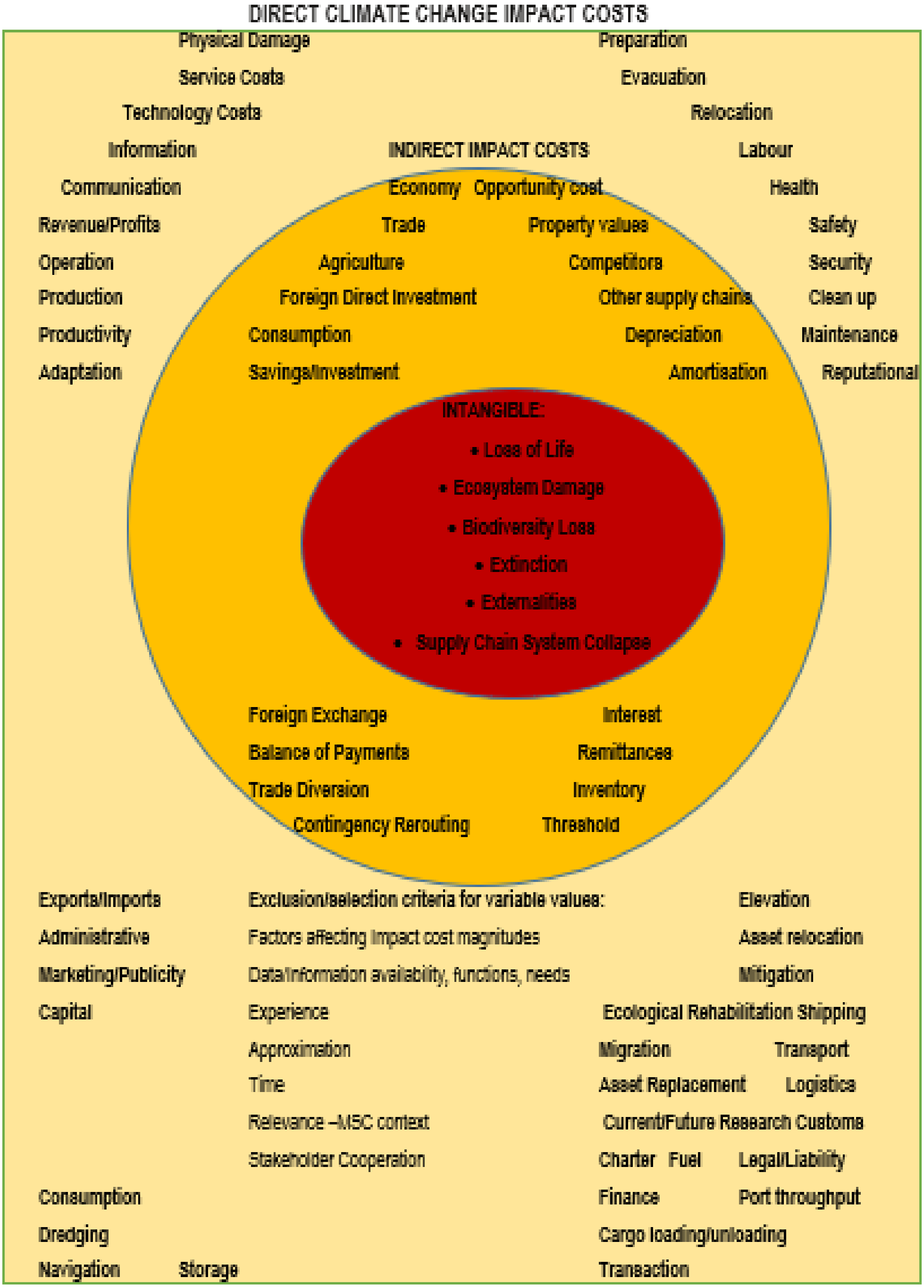
Figure 6.2 presents cost types associated with climate change impacts on Pacific MSCs. It provides objective criteria to ascertain historic, present and future impact costs in order to estimate competitors, supply chain partners and personal costs. This influences intervention timing, location and which impact/threshold costs are highest, most critical or pertinent. These can be determined using similar criteria as Figure 5.4. Impact cost magnitudes emphasise why it is necessary to react. Costs are only estimated to increase over time by numerous sources (IPCC 2015; SPC 2015; SPREP 2015). It can aid in reducing issues of moral hazard, asymmetrical information, ignorance, herding, risk aversion and information cascading, which superfluously magnify impact costs. Given states frequently ignore and underestimate private sector impacts, stakeholders learn to anticipate disruption/certain impact costs, reducing uncertainty. This minimises inaction, opportunity and maladaptation costs. A bottom-up approach assists in pinpointing how many costs are risk event specific; (whether from climate change specifically, climate variability or other disruptions including post-harvest loss/extraction), affecting estimates. This assists in managing multiple objectives simultaneously and assessing whether existing operations, investment and resources/reserves are sufficient to minimise disruption, given limited information. Adopting this approach for further events can provide a continuously evolving forecast model. As future impact cost data becomes recorded, available and prioritised, cost estimations improve for media, state and aid agencies. By identifying true risk exposure it avoids litigation risk, evaluating essential versus nonessential capacity to increase awareness of supply chain consequences.

This chapter's approach considers lifecycle cost, ecological resource security, sustainability, future existence/utilisation and stakeholder personal responsibility. It aims to overcome problems of relying on skewed media/aid agencies for unverified information estimates. Costs are often not indexed or consistent, making baseline comparisons even more challenging. A standardised approach minimises result issues of assessing impact costs from specific risk events, using multiple sources with divergent criteria. It is flexible in considering psychological reactions. This includes how average individual projected impact costs can be adjusted daily. It enables the resolution of which impact costs are generic and which are stakeholder/event/location specific. Publicly available impact cost estimates are limited, reducing the capacity for post impact-cost assessments as a key current method proposed stage.

The evaluation of impact costs improves risk awareness to survive, minimise failure and avoid maladaptation/opportunity costs. Stakeholders are thoroughly motivated by events to transform and secure a business-as-usual future. Results consider the benefits of coordinated data collection, with standardised impact cost variables, rather than haphazard, sporadic variables more complicated to analyse over time. Results/equations can be flexibly altered to consider shadow cost appraisals valuing performance, quality, ecosystem/resource/environment functions and productivity as accurate indicators of effectiveness of climateproofing adaptation and mitigation. This bottom-up approach defines spatial-temporal-geographic parameters and input variables across the Cook Islands from Chapters 3/6. This reduces challenges of ascertaining impact costs for mobile assets and monetarising values, where possible. These results consider service costs multiplied by projected event average duration/possible asset value, depending on risk. Given the time gap before the full impact is known or data is calculated and released, estimates are provided over 1, 5 and 10-year, planning horizons. Results are constrained by including multiple risk events for a year, given challenges in isolating impact costs to a specific event and determining its start/end. Limiting disasters per year is compatible with time series, probability and risk data in Chapter 5. This avoids disaster risks across years affecting impact costs. However, the chapter results are limited via the extent to which impact cost data can be estimated and variables included, especially for intangible costs including loss of life, life quality and extent of damage. It can be uncertain if costs are from general inefficiency or other disruption risks/forms of loss. There is limited sense to weighting certain impact costs as more significant over others; given data bias, subjective stakeholder perceptions (human, event or ecosystem specific) and challenges to independently replicate aggregate, impact cost estimation methods.

This method advocates using inflation adjusted market/current values for recent events including single versus joint/successive accumulating risk events – i.e. 2005 increase to 2017. 2005 is included for the Cook Islands below given data availability. This compares with 2010 for a cyclone as the most prioritised risk with highest probability of occurrence, intensity and adaptation. This allows 1, 5 and 10 year business cycles to ascertain accumulating impact cost for multiple events. The approach considers the time gap problem for information, before the actual risk event manifestation. It accommodates issues of double counting impact costs for stakeholders, given asset/system interdependency and selective recall of past impact cost, event exposure, seldom recorded accurately. The approach provides advantages of considering which supply chain, stakeholder or product characteristics magnify disruption. Which uncertain disruption costs cannot be forecast or estimated given method, data and resource limit constraints/research restrictions? A challenge exists in considering which knowledge is necessary, sufficient and feasible to estimate economic impacts. Variables can only be recorded for which information exists.

Figure 6.2: Direct, Indirect and Intangible Climate Change Costs for a Pacific MSC.



Source: Author

To value risk impacts to Pacific and global MSCs more accurately, this method's conceptual framework contribution devised marine ecosystem/resource impact cost, estimated values. To value ecosystems wherever market values exist, hedonic pricing, stated and revealed preferences, functional, preference and shadow costs including asset replacement values, were utilised. These approximate costs were based on Table 5.2 functions. This estimates related costs/values using objective data including market, recovery, replacement, resource, value adding, restoration, tourism and adaptation values where possible, rather than subjective stakeholder perceptions. It considers if costs can be assigned to each function, valuing resilience but subtracting vulnerability. To value ecosystems costs need to incorporate species/individual damage, biodiversity, geomorphology, water and sediment filtration and coastal/physical asset protection (maintenance, capital, repair, damage, erosion and adaptation). They need to incorporate productivity, tourism; preferences; scarcity, opportunity cost; economic use/function and research value if possible. Figure 6.2 presents advantages of a revised impact cost analysis versus a traditional approach. Given current risk management fails to incorporate ecological resource security, previous costs substantially underestimated projected impacts. MSC fisheries may have low economic nominal costs but high ecosystem impact costs.

6.3: COOK ISLANDS PACIFIC MSC AND ECONOMY OVERVIEW

This section presents an overview of a Cook Islands MSC and economy beyond the identification of individual MSC components, stages, stakeholders, risks and maritime resources in Chapter 5. To ascertain economic impact costs of projected climate change for stakeholders, this thesis limits itself to the specific commodity of seafood and related maritime economy products. This commodity is selected as consistently forming a significant part of Pacific regional, maritime economies and supply chains. This includes the Cook Islands case study, where it contributed 60%, 83% of Kiribati's export revenue and 16.5% for Fiji in 2015 in Table 6.1. These provided the single largest income and tax sources. Palau, Micronesia and Tuvalu also depend upon seafood as the single largest contribution to exports. It forms the top three for Samoa, Tonga and Solomon Islands. Cook Islands GDP has increased from \$173,257,538 in 1999 to \$421,781,874 in 2015 (Table 6.1), enhancing absolute impact cost possibilities from a risk event. Real GDP growth has fluctuated from 16.4% in 2000 to -1.37% in 2012 to 10.1% in 2015 in Figure 6.2.

Table 6.1. Overview of Pacific Country Exports 2016

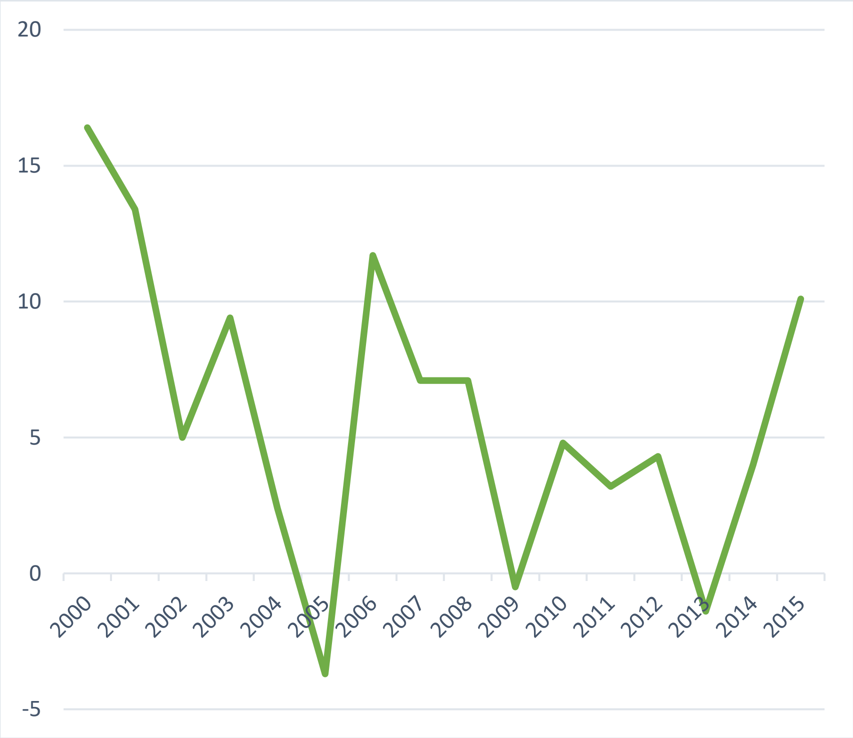
Sovereign Country	GDP $* million	Exports (Type)	Value $*	% Exports
Cook Islands	309.23	Total	34,000,000	100
		Fish	20,040,000	60
		Pearls	9,418,000	27.7
		Citrus fruit/Copra	476,000	1.4
Fiji	4510	Total	995,000,000	100
		Fish	164,175,000	16.5
		Water	99,500,000	10
		Gold	78,887,724	7.9
Kiribati	166.36	Total	63,100,000	100.0
		Fish	52,387,447	83.0
		Coconut products	4,516,177	7.2
		Copra	1,672,903	2.6
Marshall Islands	170.56	Total	527,000,000	100.0
		Copra	267,400,964	51.0
		Fish	125,953,000	23.9
		Coconut products	77,676,668	15.0
Micronesia	332.50	Total	75,400,000	100.0
		Fish	73,138,000	97.0
		Scrap metal	603,200	0.8
		Handicrafts	527,800	0.7
Nauru	50.05	Total	82,500,000.0	100.0
		Phosphate (Historical)	74,992,500.0	90.9
		Electrical lamps/lights	2,392,500	2.9
		Non-electronic machinery	825,000	1.0
Niue	7.54	Total	3,380,000	100.0
		Noni juice	1,284,678	38.0
		Vanilla	195,873	5.8
		Honey	193,376.00	5.7
Palau	324.30	Total	24,000,000	100
		Fish	21,471,632.	89.0
		Molluscs	294,281	1.2
		Raw Tobacco	251,676	1.0
Papua New Guinea	18.03 billion	Total	9.37 billion	100
		Gold	2,037,736,282	22
		Platinum based metals	1,493,437,128	16
		Copper ore	1,295,972,837	14
Samoa	994.6	Total	57,700,000	100
		Wiring	20,902,594	36.0
		Fish	11,594,554	20.1
		Vehicles	6,537,992	11.3
Solomon Islands	1042.38	Total	782,000,000	100
		Timber	522,583,560	67
		Gold	110,950,987	14
		Fish	58,982,939	7.5
Tonga	533.50	Total	18,000,000	100.0
		Vegetables	3,123,089	17.0
		Fish	2,601,320	14.0
		Cassava	1,744,286	5.7
Tuvalu	378.25	Total	28,900,000	100.0
		Fish	19,263,639	67.0
		Copra	3,221,400	11.0
		Coconut	2,023,843	7.0
Vanuatu	650.08	Total	364,000,000	100.0
		Copra	209,445,713	58
		Cocoa	115,063,984	32
		Coconut oil/meal	5,536,896	1.5

Source: Author

Table 6.2 Cook Islands GDP 2000-2015.

Year	GDP
2000	201,696,000
2001	228,922,000
2002	240,429,302
2003	263,089438
2004	269,264,264
2005	259,282,000
2006	289,680,000
2007	310,146,000
2008	332,119,000
2009	330,486,000
2010	346,399,000
2011	357,491,000
2012	372,854,000
2013	367,719,000
2014	382,800,000
2015	421,781,874

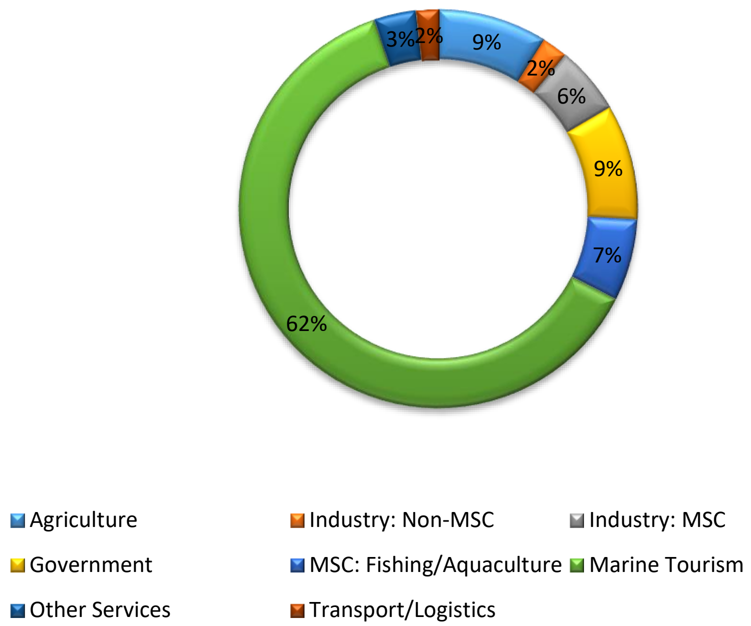
Figure 6.3 Cook Islands Real GDP Growth 2000-2015



Source: Author, based on Cook Islands Statistics Office 2016 and survey estimates.

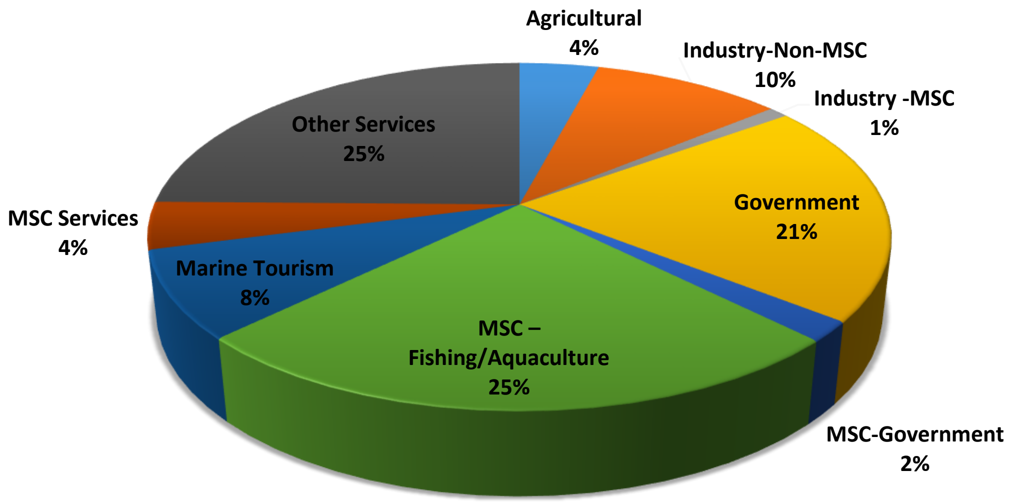
The Cook Islands economy is specifically maritime orientated. It is a small archipelago with over 90% seaborne trade, dependent on its ports for export commercial activity and the highest proportions of GDP and economic activity. Figure 6.4 validates MSC contributions to GDP with 13.9% directly and 62.3% indirectly through marine tourism. Figure 6.5 emphasises 44% of 2016 employment is MSC linked. Marine, cruise and coastal tourism including game/recreational fishing provides 85% of foreign exchange earnings (83.5% of GDP). Pearls, fisheries access fees, aquaculture and remittances are significant remaining contributors of revenue. Agriculture is more marginal, contributing 4.2% to GDP and 4% of employment. It concentrates on noni, pawpaw, citrus fruits, coconuts and maire, but without hinterland connections is highly vulnerable to ports and shipping. Limited industry exists focused on food processing, clothing, marine resource handicrafts, jewellery, gifts and aquaculture. Other commercial/ taxation prospects are restricted with no local tertiary education/research sector, a small, decreasing population, restricted land and customary land ownership and no terrestrial substantial forestry/mineral resources, except for current investigations for possible underwater cobalt/manganese mining, (World Bank 2016). The Outer Islands are highly reliant on 2 cargo vessels every 1-3 months, especially when climate conditions close ports on average 57-72 days per year. Foreign Direct Investment and Aid primarily concentrated on developing aquaculture, maritime infrastructure and climateproofing ports and logistics.

Figure 6.4: Cook Islands MSC/Maritime Economy Contribution as a Percentage of Total GDP.



Source: Author, based on Cook Islands Statistics Office 2016 and survey estimates.

Figure 6.5: Cook Islands 2016, MSC Employment Percentages of Total Employment.



Source: Author, based on Cook Islands Statistics Office 2016 and survey estimates.

Table 6.3 2016: Cook Islands Economic Sector % Total of GDP and Total Value

2016 Sector	Contribution to GDP %	Total Value $
Agriculture	8.9	37,538,586.79
Industry: Non-MSC	2.1	8,857,419.35
Industry: MSC	5.5	23,198,003.07
Government	9.4	39,647,496.16
MSC: Fishing/Aquaculture	6.6	27,837,603.68
Marine Tourism	62.3	262,770,107.50
Other Services	3.4	14,340,583.72
Transport/Logistics	1.8	7,592,073.73
Total GDP	100	421,781,874

Source: Author, based on Cook Islands Statistics Office 2016 and survey estimates.

Table 6.4: Cook Islands 2016, MSC Employment Percentages of Total Employment

Sector	% of Total Employment	No Employed
Agricultural	4.01	303
Industry-Non-MSC	9.60	725
Industry -MSC	0.99	75
Government	20.08	1517
MSC-Government	1.81	137
MSC –Fishing/Aquaculture	24.56	1855
Marine Tourism	7.90	597
MSC Services	4.28	323
Other Services	24.07	1818
Transport/Logistics	4.51	341
Total Employment	100	7554

Source: Author, based on Cook Islands Statistics Office 2016 and survey estimates.

6.4: CLIMATE CHANGE IMPACT COST ANALYSIS FOR A PACIFIC MSC

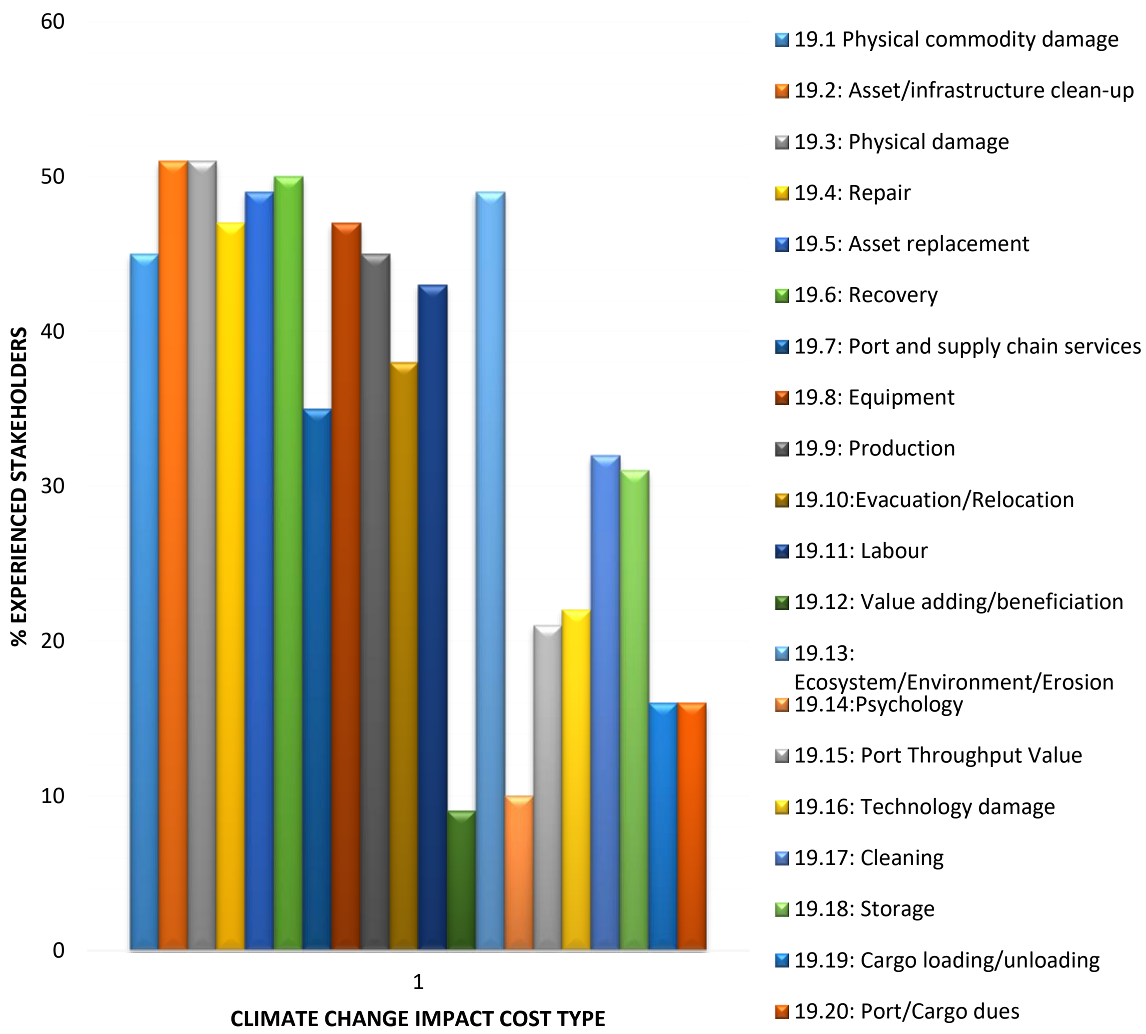
To answer KRQB, this section provides the results of consulting 99 Cook Islands stakeholders to calculate cyclone impact costs across its MSC. It provides projected impact costs for the 1987, 1997, 2005 and 2010 cyclones, determined as the most disruptive risk events. It provides the most recent examples and significant risk type, according to stakeholders contacted. Impact costs calculations are adjusted to current 2017 values. Stakeholder content analysis reveals specific impacts experienced by individuals, stages and the entire supply chain. These aim to prepare stakeholders to understand why they should mainstream climateproofing adaptation strategies in Chapter 7, in response to identified risks in Chapter 5. These apply the method to estimate climate change impact costs, using a bottom up approach. Potential impacts are accumulated when individual events cannot be separated. Section 6.14 calculates entire supply chain system, impact costs. This answers KRQB for a future event from current values. Once average impact costs are calculated, total costs are then calculated, multiplying by average probability of a specific risk occurring (Section 5.3), across divergent risk types, years and scenarios. Given existing data, the Cook Islands is projected to experience another Category 4/5 event within 5 years.

6.4.1: STAKEHOLDER ANALYSIS RESULTS FROM STAKEHOLDER SURVEY AND INTERVIEWS:

Stakeholders indicated high awareness of impact costs but frequently provided minimal detail. These were identified in question 5a/b. This was the most skipped question with 57 responses out of 100, indicating high unfamiliarity with specific impact cost estimates for 42%. This indicated frequent survey bias. Figures 6.6/6.7 emphasises how many stakeholders were actually affected by various specific impact costs attributable to a risk event. 56% experienced at least one cost, even if numerical estimates were not expressed. Data was further challenged through qualitative impact descriptions requiring impacts to be estimated more indirectly, more time consuming and likely to be inaccurate/biased rather than relying on actual records. Table 6.5 illustrates how many stakeholders remain exposed to cost consequences from future risk projections, re-iterating systematic volatility.

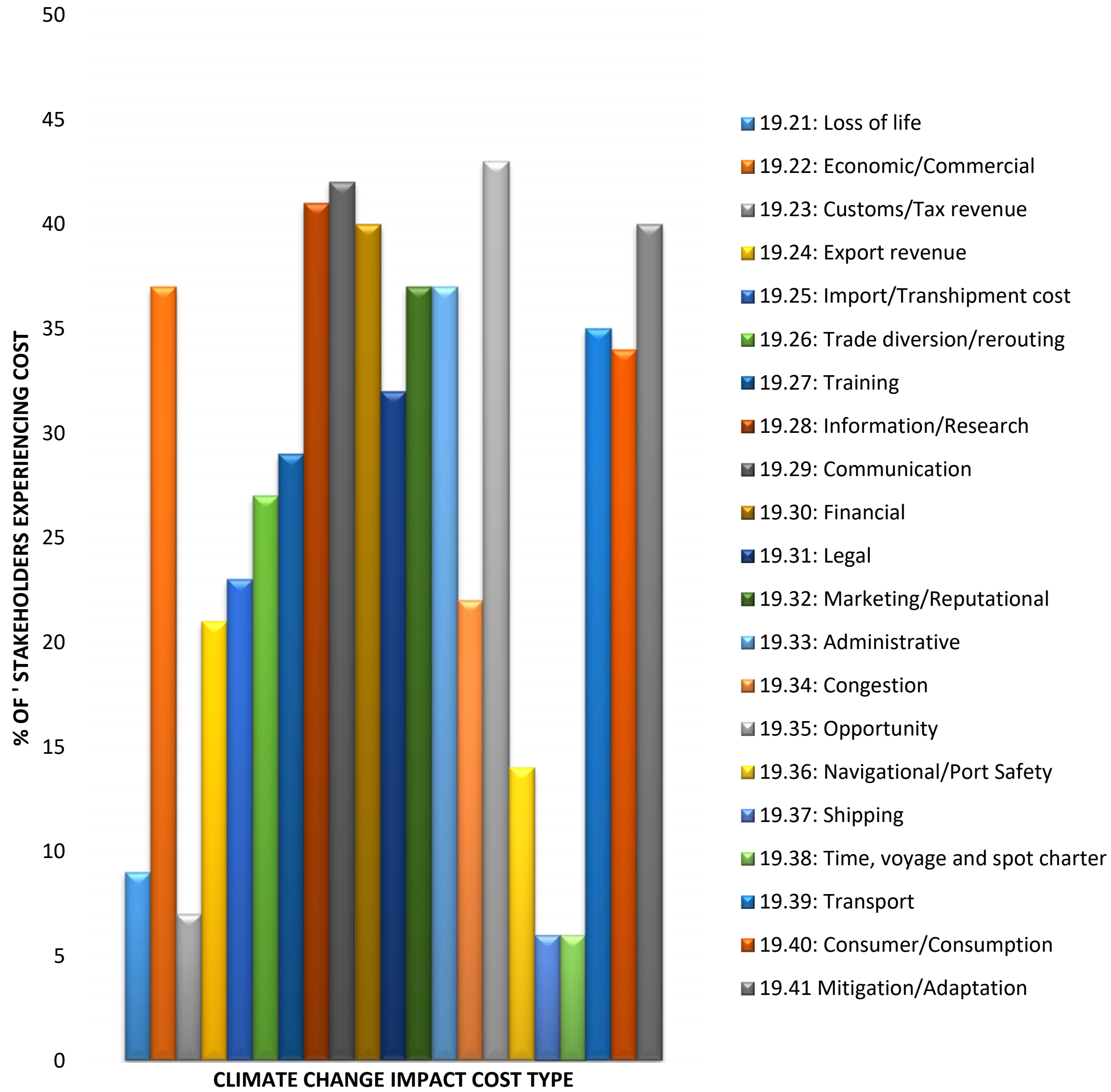
Stakeholder responses to question 5b indicated on average a cyclone event affected operations for 3-5 days. It influenced operations through direct, indirect and intangible costs, the extent of which was event, location, asset and stakeholder specific. But estimates provide a minimum indication of cross-sectoral exposure and consequences when climate change remains under-prioritised. Cook Islands stakeholders are not oblivious to climate change impact costs affecting the survival of Pacific marine resources, ecosystems and interdependent MSCs. 49% have experienced these costs as the third most frequent. Figure 6.7 shows 99% are actually vulnerable to ecosystem costs. Respondent 70 cites: "*Main priorities for our organisation include helping our country deal with negative impacts on our islands. We had 5 cyclones in 5 weeks around 2005. Beachfront land, fuel bunker depots and airports were affected for each risk event.*"

Figure 6.6: Climate Change Impact Costs Experienced by MSC Stakeholders.



Source: Author, based on Cook Islands Statistics Office 2016 and survey estimates.

Figure 6.7: Climate Change Impact Costs Experienced by MSC Stakeholders.



Source: Author, based on Cook Islands Statistics Office 2016 and survey estimates.

6.4.2: Climate Change Impact Costs to Cook Islands/Pacific Marine Resources and Ecosystems

Across the supply chain stakeholders frequently indicated ecological as among the most significant experienced costs, and adaptation constraints. All cost estimates cited in following sections derive from various sources across years including surveys, interviews, individual estimations, unpublished and published secondary references, e.g. ADB, Cook Islands Government, Statistics Office, Office of Prime Minister and media. Over $20,000,000 is being allocated to the Marae Moana, as the world's second largest marine park over 1,100,000 square miles, specifically based on these costs. Consulted participants estimated current direct ecosystem value at $NZ1,900,000,000, indirect cost at

$377,000,000 and non-use at $96,000,000. This excludes intangible values for 1,894 species. Specific risk events have repeatedly emphasised the multiple functions served by ecosystems, including asset protection, resilience and sustainable revenue generation if sufficiently valued and prioritised in climateproofing adaptation.

In 1987 Rarotonga, supply chain disruption costs from Cyclone Sally, experiencing 10m wave height, 84 knot winds and a 225 mm rain per hour maximum. Communities experienced fallen trees, coral debris off reef, siltation of water sources, 40m wide vegetation damage, a lagoon 30% shallower and 3m narrower beach. With 1.8m³ loss of ground at 75% coastal erosion at $33 per metre, and 31,000m shore loss, direct beach loss was valued at $1,841,000. In 1997, a combined cyclone/drought devastated 97% of Manihiki coral reefs, lagoon ecosystem and pearl farming, as a local book commemorates:

> *"Once again we were reminded in the most horrifying way of the unpredictability of Nature and the power of the sea. But we know like the millions of people who live at the foot of volcanoes, on earthquake belts and with the threat of tornadoes; our commitment to the land, culture and heritage means we will continue to live in those vulnerable places not withstanding their attendant risks"* (PM Sir Geoffrey Henry).

Stakeholder 30 emphasises this. *"14 metre high waves submerged Tauhumu village during the height of Cyclone Martin. Environmental clearing and cleaning were major impact costs. A major clear up of debris, rotting matter and bush, trees, sand and gravel accumulated over the village and around coastal areas is paramount.* Bleaching covered 90% of corals. Pukapuka lost 80% of its trees.

In 2005, 5 cyclones in 2 weeks re-emphasised how catastrophic successive risk events can be for marine ecosystems and dependent economies. Stakeholders detailed struggling against 10-22m high waves, 78mph gales, Rarotonga/Mangaia beach flooding and loss of 90-100% fruit trees in Aitutaki, Atiu, Mitiaro and Mauke. Ciguatera fish poisoning incidents threatened commercial viability ($530,000) with local consumer boycotts as cases proliferated from 162 in 2000, 227 (2003) to 421 in 2005. From 2003-2005 Takitunu Irritant Syndrome affected shellfish. Coral cover fell from >50% in 1987, 33% in 2000, to <5% 2001-2005 and <2% in 2006 due to several cyclones, droughts and gales. Pearl oysters fell from 70% seeded to 40% or 1,500,000-1,300,000 total. Direct ecosystem values included $680,000 per seagrass hectare, $510,000 mangroves /coastal forest, $650,000 reef hectare affected by vegetation loss and eroding foreshores. In 2010 Aitutaki's Cyclone Pat re-emphasised the hazards of underestimating impact costs with high bleaching causing 86-99.8% coral reef damage, a crown-of-thorns starfish invasion and 80% tree loss. Infrastructure lacking coastal protection faced 16m high waves and winds exceeding 100kph. Roads were blocked by fallen trees. An unexpected sub-marine landslide from a Mangaia

Tsunami landed on uninhabited coast but pulverised 1.8km of ecosystem, uprooting fisheries, pandanus trees and crops. Chapters 4 and 5 emphasise further collapses to seagrass, coral reefs and marine ecosystems, creating uncertainty for the livelihoods of producers, marine tourism, employees and consumers, if these are not conserved and enhanced.

6.4.3: Impact Costs to Producers

Appreciation of the need to conserve marine resources has been recognised not only through traditional rauii (species protected sanctuaries) but also the Ministry of Marine Resources since 1984. Its prime task is to ensure sustainable fisheries and aquaculture production for stakeholders through research, monitoring and law enforcement. They target all locally registered vessels and those present in their EEZ: *"We hope to achieve healthy, productive and sustainable pearl farmers and fisheries."* Respondents 19/20 indicated, "*We are a small island nation entirely dependent on marine resources and research. People know to an extent they need to better conserve their marine environment".* It proved fully cooperative during field research as among the most aware, concerned and active stakeholder stages, striving to understand practical implications of climate change for Pacific EEZ's. They indicated specific examples of producer impact costs. "We *have seen bleached corals–a lot of debris and you can see it not just locally but spread fairly; degraded water quality and diseased species outbreaks."* This was aided by recognition of risks and the need for cooperation/information sharing by fishing communities. "*Do not want to speak on behalf of locals because I am not one. There is awareness but a lower level of understanding as to why they are aware. People may say to stop climate change but not really understand what's behind it."* The ministry deploys fishery patrols, satellite monitoring, technology and physical farm inspections/a permit system to enforce compliance. As with other ministries, dedicated communications officers conduct workshops, media releases, social networking and other tools to promote risk awareness.

For impact costs the Ministry was especially concerned about trying to understand global trends in ocean acidification and monitoring for MSCs. It emphasised challenges in trying to quantify a species' value and the understanding the presence of keystone species, which climate change threatens. If you lose one from migration, extinction, a risk event, or overfishing; the entire ecosystem collapses. Respondent 38 noticed:

> "*Ocean temperature changes, major, deep sea and surface currents have had dramatic consequential effects on reducing fishing yields and nutrient distributions for food chains. Yellowfin tuna fisheries stopped for 20 years, only recently returning." "Fish behaviour changes according to fishing conditions. It's difficult to understand relationships to climate change."*

Stakeholder content analysis identified individual impact costs to fisheries producers. Respondent 93 noted that cyclones destroyed the environment, coral, fish life, hatcheries and equipment:

> *"Lagoon clam cages and equipment was eliminated for 6 months. No electricity destroyed our new clams. All dead clams – only recovered to 10% of capacity. Loss of internet or telephone/fax connections cost $100,000. Electrical equipment is likely to fail given a future risk event. "*

Of the total land area (61.9% forest), only 4.4% land is suitable for agriculture. In 1987 average farm damage cost $9,500, evacuation/relocation costs $50,000 for fishermen. Siltation affected seafood quality, seaweed growth and changes in fish migration patterns, tangled fishing equipment and wrecked boats. Fish prices increased greatly from $8.63 per kg fish 1987 to $13.26 by 1989. In 1997 fishing remained an integral staple of production, given limited agricultural prospects. Average trips took 5.12 hours and 2.25 fishing trips per week. Average catch rates were 2.5 kg per person per hour inner reef/lagoon, 5 kg outside. The cyclone disrupted land food supplies up to 2 years after. In 2005, seawater flooded taro patches creating 100% Pukapuka crop damage and 1.5-2 years food supply disruption.

Table 6.5 shows how specific risk events produce expensive impact costs to individual supply chain stages and producers. Total fisheries catch rates declined significantly from 3,456 to 2,988 tonnes from 2004-2006, then 2,056 tonnes of fish produced in 2007. In 2005 fishing access fees provided 0.7% GDP or $2,400,000. By 2018, total fishery yield showed a 12% decline over 4 years with more intensive overfishing (5,800,000 longline tuna. 216,000tons blue marlin; 151,000tons skipjack tuna; 19,000 mahi mahi, 47,000 tons swordfish). 96% of purse seine fisheries derived from skipjack tuna, indicating overwhelming dependency on one species. Fisheries access fees increased to $5,500,000 from 65 purse seine (40 US, 5 Kiribati; 18 Korea, 2 New Zealand) and 26 Chinese longliners. 217 registered fishing vessels and 198 artisanal fishermen face existing impact costs to fishing activities, mostly in Rarotonga. Significant revenue generated from fisheries sustains ports, trade, consumption and marine tourism. Climate change impacts on agriculture increase fisheries pressures. As species migrate/decline and marine environment conditions deteriorate, aquaculture may be increasingly necessary as a stage, contributing more to economic survival than fisheries producers.

Table 6.5 Cyclone Disruption to Fisheries Production

	2004	**2005**	**2006**
Longline	3163	3318	2868
Troll catch	293	37	170
Total catch	3456	3355	2988

Source: Author, based on Cook Islands Ministry of Marine Resources 2012 and interview estimates.

6.4.4: Impact Costs to Beneficiation and Aquaculture

The Cook Islands pearl industry remains among the most significant generators of supply chain economic activity, but reflects a core stage experiencing phenomenal, climate change impact costs. The Pearl Authority was unable to provide actual examples of risk events or proved adaptation, as mainly a marketing intermediary between buyers and sellers. Pearl production takes 18 months-3 years for seeding to harvesting, a significant income gap when compared to other livelihoods. Pearl farmers subscribe to sustainability via a lagoon management plan and farming code. One significant impact cost prompting prioritising marine resources is Respondent 8's Manihiki Cook Islands Story. "*This small island community of 280 Manihikians is all involved and dependent on pearl production. Without it there is no Manihiki or Cook Islands."* However, climate change has dramatically affected prosperity, as described in Section 5.4.3. 2016 high temperatures decreased production to a current 400,000 oysters, yet the lagoon could sustain 1,200,000.

Stakeholders expressed doubts the market is ever likely to thrive to the level of being ecologically and commercially sustainable. 50% are exported and 50% sold to over 150,000 tourist visitors per year with certificates of authenticity against Chinese synthetics and Tahitian inferior grades. Farms are solar powered but face high logistics and shipping costs, a 7 day 700 mile voyage from the remotest island. The survey results revealed stakeholders have diversified, adapted and increased risk monitoring to survive, increasingly conscious of visible costs to marine environment and production. Respondent XIV:

> *"When I started 30 years ago, pearl farming was easier. Lagoon production was favourable throughout the world. Now there's a very noticeable period when you couldn't work the farms because conditions were too warm and oysters too weak can only put them further down. You cannot work with shells for 6 months. Before we took the oysters out for half a day between seeding and extraction. Now they cannot survive beyond 2 hours. We do all the shell handling not ashore, just on the new boats received. We have to do more, – even when we have a coral outcrop with a working station"*.

The pearl gestation period delays and 3 year production process has major economic impacts when production is reduced. For 6 months farmers cannot seed or harvest. *"We the farmers are encouraging better ways of farming to ameliorate climate change because marine resources alert us."*

One pearl farmer surveyed marine resources 6 months ago. This revealed 27,000 oysters were seeded in the last 18 months. Only 10,000 pearls were formed, down from 300-400,000 per year in 1997. They experienced concern over future climate change costs. "*Most pearl farmers sell products at market and own shop. 10 years ago I was the only one. If they rely on wholesale or Pearl Authority prices they wouldn't survive, marketing does not matter. The most immediate problem industry faces to increase* *production because it's dead"* (Respondent XXX). Respondent XXX has diversified into designing pearl jewellery, retail sales and meat as further value-adding. The respondent noticed that too rough water, king tides and SLR has interfered with production methods. Heatwaves lower production whilst coral reef bleaching harms sensitive oyster habitats. Seasonal weather patterns have shifted, becoming harder to predict. Increased SST affects stress, pearl nacre quality and quantities. Producers realise consumers remain unaware of risks or costs. Demand is not supply driven in contrast to the farmers witnessing the changes. Pearl prices range from $25 for grade D to over $1,000 for grade A. Pearl meat has become a gourmet product up to $200 per kg. It is anticipated to get worse with longer drought periods and as heat intensifies with urges to dry and preserve even more fish. It moves from only a couple of days' disruption to the pearl and fishing industry, to even longer. *"To deal with vulnerability we are going to have to be even smarter –pay more attention to history, science and the environment."*

Respondent 55 experienced longer working hours and delayed production concerns: "P*eople need to be aware business is not immediately viable. You need to survive 18 months minimum without a break as a business; so pay attention and be effective stakeholders."* He remained not really sure of personal implications and noted the decline in island population. A higher population entails a more sustainable economic situation. Population increased from 200-300 in 1960's to 600-700 in 1980's – now 280, based on psychological and economic impact costs specifically linked to 1997's catastrophe. During 1997 RNZ Hercules 3 flights evacuated 100 people per flight, but no consideration was given to repatriation. Respondent 86 estimated pearl farming production costs exceeded $100,000,000 *"One of the whole islands was displaced and some have not gone back since 1997".* Respondent 91:

> "*Cyclones destroy infrastructure which cannot be insured." "Heatwaves stresses occur almost every summer in the last 10 years and Cyclone Martin destroyed all my farm infrastructure." "Heat affected farm reduced my production each year by 20-50%."*

The Cook Islands pearl farming industry's collapse re-iterates the need for MSC and other supply chain dependents to incorporate sustainable resources, when planning for business-as-usual scenarios. It illuminates how costly disruption can be, not just to individuals but to stages and entire economies based on direct and indirect impact costs, identified in section 6.1 but seldom considered by many. In 1987 pearl farms increased from 8 to 26 a year later. Pearl income was at $600 per person per week minimum. In 1997 over 200 pearl farmers operated with over $1,000 minimum income each. Due to 2005's cyclones, pearl fishermen's incomes decreased to $5,000 from $9,250 in 1997. Wages shrank to $435 per week, adversely affecting employees' disposable income. An inexpensive permit cost $20 for 5 years. Pearl production export value fell to $1,600,000 (2006) from $18,400,000 in 2000. Although production prices, revenue and production increased from 2003-2006 as Table 6.6 indicates, actual exports were adversely affected by damaged ports, roads, shipping delays and other supply chain stages. Fish consumption decreased from 57.4 kg per capita to 20.4 kg. Weekly fish dinners decreased from 4.7 to 3.3kg. Wages remained $5/6 per hour from 2004-2015. Two out of three fish processing plants failed.

In 2007, aquaculture produced 186,725 pearls -$2,200,000 excluding jewellery/crafts, 3,058 clams worth $7,645 and 16,80 kg tilapia was $12,267. It exported 1,500-1,600 aquarium fish. However, aquaculture became affected by cyclones/tsunamis, disease, world market fluctuations, overstocking and poor marine eco-literacy. By 2010, pearl production fell to $300,000. 10 aquarium farmers existed. 25 tons of trochus was produced per year. Climate change indicates significant opportunity costs not just from existing production but a sector where only 15-20 businesses survive, representing a 90% conditional probability failure rate attributable to various risk factors.

Table 6.6 Pearl Production Output Around 2005 Cyclones

	2003	**2004**	**2005**	**2006**
Price per pearl NZ$	20	21.50	22.50	$25
Pearl revenue	1,0120,000	1,104,000	1,635,00075	2,334,500
No of pearls	50,600	55,200	72,670	93,300
Cook Islands revenue	674,667	738,000	1,090,540	1,556,393

Source: Author, based on Cook Islands Ministry of Marine Resources 2012 and interview estimates.

Stakeholders are retaining current fishing practises in the absence of specific adaptation strategies and remain uncertain about attributing fluctuations to climate change. Respondent 51 expressed ignorance of impact costs and risks or links to natural disasters, uncertain if from climate issues or just overfishing, increased vessels, productivity and poor lagoon or ocean fisheries management. They have experienced ciguatera fish poisoning. Certain stakeholders expressed more concern not for fisheries but increased requirements to minimise emissions and other technical/regulatory requirements. Many are especially concerned about making changes without enforcing them for competitors. As fishing operators they experienced reputational risk increases for tourism. Physical risks experienced increased salinity for boat corrosion, swells and storm surge, before climateproofing the breakwater. Many fisherfolk sheltered away from the exposed islands' sides or inland with a mobile boat and trailer. Respondent 93: *"In 2005 5 cyclones hit Rarotonga. Business property had to be stabilised. Fishing activities had to cease until the storms had blown over. Fishing recovered within a month. Business experienced 2 weeks delay in getting back up to normal operations."* Respondent 47 as a fisheries observer noticed catch rate fluctuations with El Nino seasonality, warmer temperatures and species migration from changes in nutrients. More areas experience lifeless coral. Fishermen have not seen many sea urchins. Many species are overfished and decreasing, increasing marine ecosystem costs further. She cited global population increase as major concern placing even more pressure on Pacific marine resources. People are staying out longer and increasing the amount of effort to catch same volumes across islands. "*Fishermen - always changing with the world for an income and food source. They have to, in order to survive and remain.*"

6.4.5: Impact Costs to Seaports

Cook Islands ports continuously experience severe climate change impact costs, with multiplier effects across supply chains including close proximity of utilities, roads and logistics services. There are no back-up port options other than offshore, western side mooring at Aorangi Passage. Respondent 74 prescribes the port's main priorities are to "*grow the business and asset risk management.*" Each event remains a concern: "*Because it would damage the wharf infrastructure.*" During a risk event, stakeholders are notified via a siren. An informal agreement includes relocating as many mobile assets as possible inland, as individual users' responsibilities. Vessels are relocated. 100 containers on the wharf on average are exposed. The port remains concerned about climate change. It is prepared for the next 20-30 years for various risk types but projects with 80% confidence the main port can become operational in 24-48 hours, based on experience, although at significantly reduced capacity. Respondent XVI notes that cyclones are getting bigger:

> "*The more intense cyclones – the less chance buildings will remain in good conditions. We backup every weekday manually and automatically to a remote site. We've faced problems getting staff back in time. Sometimes with cyclones you receive only 6 hours warning – tsunamis only 3! For training, we have exercise to familiarise staff and port users, specifically targeting management and leadership, who others turn to. We have emergency plans at gatehouse, canteen and main office*"

Specific events have created port cancellations and delays, reducing revenue and performance aside from physical damage:

> "*We have a good working partnership with other agencies locally and internationally. One of our jobs is to monitor weather for cyclone/risk formation and determine its hypothetical route. From the Caribbean our aim is not to take it for granted. You can only do as much as you can but that's better than doing nothing.*"

Even with adaptation, stakeholders avoid complacency given numerous past seaport failures. They note that the severity of climate change is increasing, and seems irreversible:

“*Maybe climate change will be worse tomorrow …. it doesn’t mean you put infrastructure to the standard and just sit back and say we don’t know what severity climate change will be. 99% cargo comes from ships. The risk is present even if low. If a ship hits the reef it will block the channel.”*

Repeated impact costs during each stage emphasise how each day of a risk event’s existence can challenge a port’s capacity and other stakeholders to remain functional and commercially viable. One event can stall development prospects for over a decade, as ports divert funds to recover, even though projected port lifespans use 20-30 years on average as planning horizons. Reduced port capacity and throughput increase value chain expenses, causing pearl diversion to air freight; delaying consumer imports and limiting tourism volumes. In 1987 Cyclone Sally caused direct port damage $NZ 2,800,000; $8,400,000 in coastal damage and protection, $1,910,000 maintenance, insurance loss of $33,622 and $12,800,000 impact repairs. (ADB 2010). In response consultants originally proposed a 30m cyclone and flood buffer zone of development, not enacted. In 2005 12-metre-high waves from five cyclones damaged Mangaia harbour affecting 570 people. Rarotonga wharf failure cost $2,200,000 (US$ 1,411,700) (ADB 2010). The repair cost was $700,000 (US$ 496,000). Each average cargo takes 2-3 days per loading. These events delayed logistics between 1-4 weeks. Atiu Harbour Rehabilitation started after cargo was disturbed for 18-21 months, costing NZ$8,019.58. In 2010, Cyclone Pat affected Aitutaki port with 17 metres higher than normal waves, costing NZ$113,186 in revenue foregone to domestic shipping. Total cargo throughout included 2800 tons domestic cargo, 11,315 tons conventional cargo, 25,900 containers, 15,893 tons of liquid bulk and 3460 TEU. Cargo dues decreased $4578, $43,105 in ship services, $20,457 in wharfage, communication costs 2120, fuel $3,108, wages $7,931, equipment $1,160, and $11,859 in insurance (Cook Islands Port Authority 2011/2014/2017).

If Avatiu Port experienced a current risk event in 2017/2018, its impact costs would be even more significant with over $47,750,000 total replacement value according to survey/interview respondents. Over 50 vessels, 58,250 tons and 2,376 TEUs of cargo would be affected directly. Specific costs are summarised in Table 6.7. These can be multiplied over the time period, stakeholders and assets for each risk event to answer provide the total impact costs. In 2016, current assets are worth $4,455,242, revenue $3,771,360, expenses $3,100,334 and port taxed revenue provided $364,528. Labour costs were $700,917, communications $13,913, fuel $85,301 and electricity $41,481. Social costs included support to marine surveillance, inter-island domestic shipping, local Voyaging Society, MMR and logistics firms.

Table 6.7 Avatiu Harbour Port Revenue Charges

Port Dues	Port Services:	Local vessel berthing fees:	Cargo Marshalling
$36 per visit <250 GRT	**Water** -$66 per visit;	**Charter/pleasure** $0.70 per m per day;	Forklift – 30+ ton $107.50;
$1793 251-1600 GRT	Garbage $76.50 per day.	Subsistence Fishing $0.30 per m per day	3 ton $13.50. Penal rate >30 = 51.50 per ton
1601 GRT+ $1.25 per GRT per visit;	Light $100 per night;	Inter-island $0.20 per m per day	Ramp charges -$5.30 per boat per year
Cruise -$0.55 per GRT per visit	Reefer plug in -$95 per day;	Local commercial fishing/tourism = $1.5 per m per day.	Diver -$38 per boat per year;
International fishing vessels $380 <500 GRT	Delay charges Tugboat -$214	**Import/Export:**	Penal rate costs.
$850 500-999 GRT	Linesman $28 per person per hour	FCL per TEU= $237 LCL = $182	Vessel delays $153 per hour
$0.95 per GRT per visit) (1000+)	Pilotage $150 per person per hour	Shipper's unit $206;	After hours $272.50
Non berth $0.14 per GRT per visit <1000;	Tug hire $264 per hour	Break-bulk: $6.50 weight per metre³,	Weekends $435
$ 0.20 per GRT per visit 1000 GRT+	Cargo dues $1.20 $1 –category 5.2; $0.5 domestic	Drums/Tanks = 1$13; Fuel = $11.50 per 1000 l, $22 per 1000 litres.	wages/labour costs $28 per hour;
Port vendors -$20 per cruise day	**Container clean up**	**Storage**	Forklift transfer -
$10 per non-cruise day	Reefer $42.50 per TEU	20 TEU $58 per day FCL 40 = $47.50.	30+ tons = $342 per TEU hour
Ramp hire $115,60	$27 general cargo;	Break-bulk $3.50 per cubic weight metre.	$61 per hour,

Source: Cook Islands Port Authority (2017).

6.4.6: Impact Costs to Shipping

Marine economies such as the Cook Islands incur greater impact costs for shipping, than other nations, lacking economic hinterlands and terrestrial resources. Islands remain dependent on infrequent shipping services to provide most staples, ranging from container shipping once per fortnight in Rarotonga and Aitutaki to once per 1-3 months. High transport costs and few returned exports decrease commercial viability further. Even Air Rarotonga rely on shipping to provide fuel to the outer islands and the patrol boat. Until 1997, Silk and Boyd, the former main shipping line, were subsidised $286,000 per year. Contacted respondents repeatedly indicated preference for it to be reinstated. Respondent 13 survived 22 years estimating $1,500,000 of business, wages $500,000, fuel $700,000 per year in costs, using 6,000 litres of fuel per day. During a cyclone/event the vessels evacuate Avarua, taking shelter in the leeward island side. Climate change events have previously diminished agricultural and fisheries productivity up to three years after an event, with damaged infrastructure generating congestion and delay costs. Each delayed voyage costs $24,000 -$30,000 fuel and $200,000 in other costs. Four shipping companies experienced bankruptcy faced with high costs including port and cargo dues increased to restore assets.

Respondent 38 operated in fisheries and shipping. Specific impact costs experienced included responding to increased international shipping legal requirements to lower emissions via slow steaming, an expensive solution, adding to costs and disruption for average voyage length. He needed more voyages to be commercially viable. This is potentially problematic given economies of scale, low unit costs, profit margins and high fixed costs encountered by many shippers. The foremost concern was curiously not directed to specific risk events but increased legal and administrative costs targeting mitigation. Respondents XXI-XXIII and L recognise climate change concerns for shipping including emissions *"To know what to do as baseline data before we can consider the impact and plan to adapt in the future."* Most vessels are perceived as sufficiently robust to extreme marine environments and adverse climatic conditions, and mobile enough to shelter with sufficient forecasting information available. However, respondents indicated concern for vulnerable customers/exposed cargo, changing seaports and diverting trade as shore-based infrastructure experienced far more costly consequences. Respondent 37:

> *"The difficulty with Avatiu harbour, when cyclones do come from northwest direction with south-easterly prevailing winds. Vessels enter only under calm conditions given no direct protection over entrance. The seawall is entirely constructed of large boulders, which may fill the harbour up. This could damage problems worse than before."*

From 1990-2017, the Cook Islands lost 50m of shoreline from SLR and other events. One of the shipping companies raised questions about climate change's impact on residents' livelihoods. Respondent XII states that people should be given a chance to improve resilience:

> "*Over the years we've talked to a lot of research consultants to promote opportunities and provide improvements in logistics." "The government doesn't really cover it. It's all very well to say we'll subsidise fuel for interisland shipping but costs are so much more. We have a ship fully classed and manned to international services and we pay a premium to ensure quality. But government seems reluctant or slow to understand it …. it has to be commercially viable."*

Respondent 57 noted when climate change caused congestion 5 days out in the ocean, given existing harbour constraints. Due to airport height restrictions, vessels cannot enter when planes take off/land. They noticed even greater reliance on imports, after New Zealand agriculture biosecurity restrictions. Now they are even importing cargo such as cabbages, coconut products/tropical fruit and vegetables, for which the Cook Islands possesses a comparative advantage. Even greater pressure exists from tourism's growth and growing demands for imports. Other imports include motor vehicles, steel, fuel, food, cement and building materials on average 130 TEU's per voyage.

Shipping impacts have caused disruptions to other nations' supply chains, if vessels are stranded. It could be 5 days before the ship managed to leave. In 2010 the Aitutaki cyclone caused a fuel shortage and limited supplies for 28 days, given no safe shelter. People bulk-purchased fuel/essentials wherever possible. Vessels were tied out on shore to trees. A narrow 3-4m harbour mouth opening provides just enough room to turn around under calm conditions. Climate change is perceived as here to stay – as are natural disasters. "*Yes, we are aware – people like visuals not if it's all verbal or written. They talk about weather patterns. I can see the change around me compared to what we were used to before."* Tsunamis only provided hours warning to move mobile offices and vessels compared to 3-4 days for a cyclone. The company reacts since losing 80 containers on a wharf. The shipping company noticed vehicles multiplied from 1 motorbike per household to 2-3 plus 2-3 cars, increasing emissions. In contrast respondent 73 states the business aim is to survive and grow:

> "*5 Cyclones disrupted telecoms and Internet connections for a week in 2005. Although our data and systems are now in the cloud so the rest of the world can keep working, even if Rarotonga has no internet or power. Systems are fairly robust but outages are expected with a direct hit."*

In 1987, several smaller boats sank. 118 yachts and 224 fishing boats (52 commercial/tourism operated) were impacted, many discouraged by the unprotected, cyclone ravaged seaport. In 2005 28 round-trip shipping schedules experienced high trade diversion costs to Samoa and Tonga. General cargo, shipping impact costs were $2,500-$2,800 per container, Reefer cargo $3,500 per unit and $5,500 for container cargo. For Cyclone Pat reputational costs caused a fall from16 bulk liquid carriers to 12 in 2010.18 cruise ships decreased to 12 in 2010 and 2011. Fishing vessels decreased to 60 – an average 200 tons. By 2018, potential climate change threatens $400,000 per year total in inter-island shipping costs. Of 318 vessels, 92% are small powered fishing vessels, 4% commercial, 4% sports and recreation. Average crew remain 1-3 people with a catch rate of 36.8kg per hour. A high dependency on shipping remains. Air Rarotonga takes at most 13 people and minimal freight, on average 6-10 people, making shipping more vital as a link to the outside world. From 2005 cyclones several harbours needed to be upgraded. "*In the past vessels were delayed 10-12 weeks after events but that hasn't occurred in years."* Respondent IX notes specific impact costs:

> "*Problem of boats tied up at reef unsheltered anchorage, using island barge for transferring cargo challenging among the waves* and *possible problems of bypassing the islands for the next 4-6 weeks. One cannot tell Mother Nature a straight path of the wave or to deviate."*

Respondent XIII notes "*At least 1 small ship has been swamped by waves, others caught in storms. The effects of a Samoa cyclone etc can be felt 800 miles away."* Outer island anchorages are exposed reefs a mile from shore. Additionally, shipping is dissuaded from normal business operations due to migration and insufficient return cargo volumes. "*The population is really gone down. It's not viable to take cargo there because it's so far."* He estimated transporting renewable energy parts saved $3,000,000 of imports each year or 100,000l of fuel per month. Shipping echoes other MSC stakeholders in being willing to recognise impact costs to vulnerable communities, businesses, customers and crew:

> "*The limit is the limit for the environment but what is ours? Islands are disappearing, reefs are getting more acidic. Land is so important to survival –the oceans are going to be even more so. We didn't play much of a part of it and contribute, yet we are facing it. What are we going to do to minimise the effect on us and those around us? 'When the ocean and world are destroyed –we will be destroyed*!"

They remain conscious of personal costs. *"I believe everyone should be thinking about it; not ignore those or expect everyone else to do something about it but ignore them. People in the future will be able to say: We did something that matters. We secured and dreamed of our future."*

6.4.7: Impact Costs to Roads, Logistics, Storage and Distribution

Like other chains in the maritime logistics system, road transport is also subject to adverse impact costs from natural disasters with obstructions and interruptions to producers, importers, exporters, consumers and marine tourism sector. Many gravel/sand roads on outer islands have also perished. However, sand mining erodes natural coastal defences. Using coral reefs to pave roads, especially post-cyclones, accelerates damage to ecosystems, fisheries and tourism as an under-investigated impact. In 1997 Manihiki lost 90% of coral and gravel roads. As Table 6.8 demonstrates, logistics experienced less disruption than other sectors. The 1997 cyclone damaged 27 cars and 31 vans. 43 cars and 3 trucks were lost in 2005's cyclones. This produced an estimated car value $2,750,200 in 2005, vans $1,753,300; and transport equipment $698,500.

Table 6.8: Cyclone Impact Costs to Logistics Assets.

	Car	Truck	Van	Other
1996	47	3	79	4
1997	133	6	123	2
1998	106	18	92	2
1999…	212	25	122	1
2003	400	55	192	10
2004	293	41	89	14
2005	350	58	131	35
2006	307	55	141	36
2007	355	65	163	18

Source: Author, based on Cook Islands Statistics Office 2011 and interview estimates.

Stakeholder content analysis indicated frequent awareness of general impact costs for logistics including average time they were affected. However, they were less capable of determining monetary values for ones experienced, information relating to risk/vulnerability, or factors determining conditional probability of asset failure. Respondent 70 stated assets did not fail often. "*Not often. Airport took two days to recover. It's a bit hard to describe vulnerability of assets, you can glean from above."* Few logistics, stevedoring, storage, recycling and shipping companies exist, ensuring even greater costs for those stakeholders beyond the sector whose business relies upon them to operate. They frequently indicated constraints under normal business conditions amplified under climate change. Respondent 11:

> "*We can only withstand actual losses for so long. Otherwise we will work somewhere else where the revenue is more sustainable. If they talk about infrastructure, service delivery; improving outer island links, they have to invest in improving outer island transportation links."*

They consider labour shortages from migration represent a major cost, indirectly related to climate change, whilst tourism growth generates the demand for imports preserving business. They were especially concerned about dependency on the port and 2 circling roads, given flooding, road blocks and recovery costs. To maintain supplies, moored unprotected vessels out the harbour and transferred via barge. "*Biggest issue is the port. If it shuts down it would cripple things but we are flexible enough, looking at what's happened in the past to fight onto an even keel"* (Respondent 12). The backup port Aitutaki is exposed anchorage in a cyclone's general path. Most businesses have some insurance. They recognise public sector reconstruction would minimise commercial losses from reduced private sector activity. However, businesses did not factor securing baseline needs or recognising the majority of costs experienced. "*The onus is on people themselves to act."* Many recognise extreme costs deriving from port, customs, customers and shipping firms from any delays, needing to recover and prioritise adaptation solutions. *"If I have to sign up to the benefits of half an economy not to lose benefits and survive then fine." (Respondent XXIII).* They consider most other stakeholders to be fairly aware about climate change and disasters, favouring cooperation to minimise costs, though not too sure of 1.5m SLR impact.

6.4.8: Impact Costs to Customs

Climate change affects customs' primary objectives to facilitate trade, protect against foreign competitiveness threats and ensure security. Increased globalisation pressurises Cook Islands 24/7 operations with only 10 staff. During risk events damaged systems, infrastructure and delayed vessels enhance congestion and reduced performance, lowering customs revenue. Over the past 3 decades however, climate change had less impact on revenue generation. In 2006, customs revenue experienced an estimated $6,000,000 loss in fees from 5 cyclones based on trade diversion, physical goods damage, reputational and other costs. Tax rates remained 28% local, 28% foreign companies. Since July 1 2006, customs tariff revenue has disappeared apart from excise duties, substantially reducing contributions to tax revenue and lessening impacts for importers, wholesalers, consumers and other stages.

Customs are doing more and more with fewer resources. Its outdated software costs $120,000 to retain operations. Customs records are backed up, aiming to operate within 24-48 hours. Respondent 10 mentions the removal of over 95% of tariffs and dues to simplify work and open trade with exemptions primarily on those that cause social or environmental harm, i.e. liquor, tobacco, petroleum, carbon emission taxes and excise duties. If they need international assistance the Customs Act makes provision to speed and facilitate humanitarian aid goods within a 6-month window. Currently customs agents are considered unaware of actual impact costs and complacent in certain areas. From past experience the emphasis is on import/export agents to be proactive with risk management to minimise costs.

6.4.9: Impact Costs to Imports, Exports and Transhipments

Seaport damage and shipping delays from climate change substantially increase pressures for consumers, producers and retailers, as import/export volumes diminish from physical commodity damage, consumption income and production loss. In 1987 crops experienced a 6-month delay. Exports decreased from $7,100,000 in 1987, $4,300,000 in 1988 (38.89%) and $2,800,000 in 1989 (35.71%). Imports rapidly increased to allow for increased food security, lost goods and reconstruction from $26,300,000 in1986; $33,600,000 (27.88%) in 1987; $42,300,000 (25.71%) in 1988. In 1997 Cyclone Martin flooded taro crop and destroyed 100% pearl exports. (50% were for Japan then Europe, Australia, Hawaii and mainland USA). Higher imports and lower exports, adversely affects the balance of trade, increasing debt deficit and lowering reserves, as indirect supply chain costs. Over time, climate change increases costs as Pacific maritime economies become less self-sufficient and more globally integrated, thus more dependent on imports.

2005's 5 cyclones caused a fall in export value from 2004 $7,800,000; to 2005 $5,200,000 and 2006 $3,500,000. Import values rapidly increased from 2004 $76,113,000; 2005 $80,998,700; 2006 $99,800,000; 2007 $98,700,000. Specific imports are summarised in Table 6.9. In 2006, fisheries were 60% exports with $92,000 from exporting live reef aquarium fish; $692,000 fresh fish exports $1,327,000 pearls and $2,000 from pearl shell. The US comprised 8% of exports, Australia 34%, Japan 27%; New Zealand 25%. In 2007 fisheries contributed 79.4% exports. $1,100,000 import value, $2,200,000 exports excluding pearls. Pearl exports fell from $18,600,000 in 2000 to $1,600,000 in 2007, demonstrating risks to beneficiation, as one stage indirectly impacts multiple other stages. Food exports (mostly New

Zealand) fell from $2,300,000 in 2005 to $564,000 in 2011. In contrast, food imports increased $110,000,000 or 32% in 5 years as crops and fisheries not only took significant time to recover production but trade faced reduced capacity and performance from damaged ports, logistics and utilities. Cyclone Pat's 21% decrease in exports and 42% import increase in a single year, further affirms how costly individual events can be when stakeholders refuse to be proactive in diversifying risk and promoting resilience.

Table 6.9: Specific Cyclone Impact Costs to Imports

	2004	2005	2006	2007
Food	$26,509,000	$27,866,000	$29,914,000	$44,980,000
Crude materials imports:	$4,236,000	$4,587,000	$3,702,000	$4,945,000
Minerals/Fuel	$9,080,000	$10,452,000	$34,137,000	$33,521,000
Machines/Transport/Equipment	$26,713,000	$24,413,000	$34,789,000	$62,780,000

Source: Author, based on Cook Islands Statistics Office 2011 and interview estimates.

6.4.10: Impact Costs to Wholesalers and Retailers

Although imports and exports incur high climate change impact costs across trade networks including wholesalers and retailers, business interruptions for extended time periods, infrastructure/inventory damage, reputational risk and actual failure become more of a concern. In 1987 nine shops existed in Manihiki. After its 1997 cyclone only two survived – a 71% failure rate. Credit costs increased from $40,268 to $49,864 from perceived greater risk. Reputational loss deterred foreign investment including a lack of support and finance for the private sector, limiting recovery. This not only applied to Manihiki but also the mainland. 31 new commercial businesses were approved in 1997 worth $3,200,000. In 1998 17 were approved worth $2,900,000. In 2005, most businesses ran out of supplies, causing stockpile hoarding and shortages. Businesses closed 1-3 months on average. Trader Jack's alone, a waterfront tavern, lost NZ$600,000. Tourism numbers fell 5% costing $1,500,000 direct (excluding reputation damage). 300 tourists were evacuated. Certain hotels experienced rubble to revetment, flooding and coastal erosion, except sand accretion increasing sand to Pacific Resort. Building materials were 100% lost. Businesses approved decreased from 66 worth $10,800,000 in 2002 to 36 ($5,500,000) in 2004 and 36 ($5,900,000) in 2006, reflecting decreased business confidence, resources and financial sector willingness/capacity. In 2010, 17 retailers//wholesalers were damaged costing $370,650, on average $40,000 per shop. One warehouse damage was $3,550; replacement cost $27,000 and trader's shed $19,500.

Recently retailers/wholesalers have become more sensitised to climate changes' presence, its influence on commercial activities and the need to cooperate with other affected stakeholders. Respondent 75 said their main priorities are to work with funding agencies to prepare SME's to be more resilient to climate change.

"Strong winds and sea waves destroy businesses like buildings, equipment, plant stock etc. Salt water penetrating into the soil affects planting land and drinking water and these can wipe out communities in low lying atolls and reduce arable land elsewhere, affecting food production and ultimately businesses. It destroys businesses most of which are not insured and not assisted in rehabilitation, therefore affects people's livelihoods.'

Respondent 46, a plumbing business, recognises impact costs can bring opportunities for sufficiently flexible and conscious stakeholders against competitors, with $600,000-$800,000 damage to private water tanks needing repairs and replacements in 2010. The company rebuilt 70 homes, 10 businesses, enduring only minor workshop damage. As a community member, he was concerned about marine tourism's sustainability:

"Are we willing to spend tomorrow, simply to splurge today? Interesting as to when do you intervene? We can't stop tourism! We should ensure they take more responsibility for their actions. Don't see this risk improving in the future but not sure whether can make any real change, except to slow the pace. "

The Cook Islands regards big businesses as those employing five employees or more, but impact costs remain potentially similar across Pacific MSCs and global equivalents. Frequently the private sector, regardless of size, lack the same awareness, resilience and funding adaptation capacity of communities and the public sector. Respondent 19 stated*:*

'Only aware of recent cyclone that hit Aitutaki damaging buildings, stock and equipment. No businesses were assisted after the cyclone, so several retail shops and a bakery never recovered. We do not have information on businesses that failed because of cyclones. Many took at least 28 days to recover".

Respondent 67 (Business/Retail) said that storms, floods and cyclones impact on the safety and security of local communities, tourism, industry and social services in its ability to provide services and cope:

"The most recent disruptions in 2005 took 6-12 months to recover. Public services, road and water infrastructure, food, homes, vehicles and the tourism industry are specifically affected. There was a certain amount of loss or damage, which always add up to the millions of dollars. However there has been minimal loss of life from these events. It could have taken 2-3 days before operations resumed to as long as 12 months before it was fully operational."

Catastrophes threaten minimal reserves and profit margins of small-to-medium sized enterprises, neglected by the financial/insurance/government sector. NGO aid fails to recognise economic survival remains conditional upon businesses, their capacity to produce, employ, import and export. Stakeholders expressed notable concern about not being a priority by those with funding, information and communication capacity. Respondent 29 for the commercial sector noted "*If a tsunami hits Rarotonga from Trader Jacks' to the airport – everything would be wiped out. Core businesses are all one main coastal, exposed coastal route. If a disaster struck the economy is messed up, if airport and port are gone – everything is gone!"* They recognise climate change experts are not business professionals, sensitive to client requirements and commercial constraints. Businesses lack support from aid/state to face the aftermath recovery period, including calculating how to survive/minimise disruption when crops are wiped out, e.g. bananas and pineapples take 10 months to fruit. Once individuals understand businesses importance to communities, priorities may change regarding this exposed, supply chain node.

6.4.11: Impact Costs to Fuel and Utilities Suppliers and Infrastructure

As with other stages and sectors, stakeholders plan business-as-usual conditions, operating on short term horizons. However, systemic risks from climate change mean that impact costs to one utility or infrastructure development produces multiplied cost consequences across individuals and stages. Official impact cost estimates therefore underestimate expenses. In 1987 damage to power/water cost a total $407,500, ($90,100 from waves). Other utilities cost $1,318,768. In 1997 a drought decreased water supply 20-50%. Water restrictions were applied, reducing volumes from 40-60 litres to 5 per second. As Chapter 5 emphasises, each stakeholder remains vulnerable to these perpetual costs. In 2005 30-40% electricity, half of Mangaia airport and its entire port was destroyed by a 10m high wave. 543,000 kWh lost caused a revenue impact of $300,000. In 2007 Rarotonga bridges were ruined by rock and road debris. Solar panel damage exceeded $30,000. Rarotonga has 5,400 water connections but charges 0 tariffs, even during drought conditions. Utilities and fuel infrastructure received an estimated $1,800,000 commercial costs.

By 2010 government departments recognised how many stakeholders needed utilities infrastructure, prioritising this sector for adaptation as public goods with positive externalities. They focused on risk monitoring, conscious of human survival not just business as for other stages. For Aitutaki cyclone winds were up to 240kph (current building code limit is 176kph). It caused flooded roads, bridges, and sea surge. Fallen trees and electric-powered water supply affected 568 homes. Water supplies were damaged for 3 weeks. Power lines were uprooted and entangled, losing 80-90% electricity, disrupted between 3 weeks to 1 year. The estimated cost was NZ$2,300,000/US$1,600,000. Climateproofing infrastructure has become a new priority integrated into engineering designs in contrast to other nations, responding to visible risks and impacts. Respondents 34/35 mention the land is vulnerable to coastal erosion and other geophysical constraints, amplified by repeated risk incidents. Structures need elevating, relocating or adapting. They have experienced tsunami warnings requiring evacuation routes, built seawalls and coastal defences. Large rocks and waves have smashed into assets. They express concern when the private sector fails to adapt, especially coastal tourism operators increasing latent impact costs to public infrastructure. Roads are sealed with bitumen - engineers perceive these to be safe from heatwaves and changes in temperature/moisture etc.

Respondent 37 follows this approach of "*Prepare for the worst – hope for the best",* mentioning how vulnerable government infrastructure remains. "In *2005 buildings were smashed down –a lot easier to build new than renovate."* During disasters supply chains are highly vulnerable to government operational responses and communications remained disjointed for local communities. Some used caves as stronger than buildings for shelter. Respondents 45/46 mentioned how the Cook Islands still experience exposed electricity cables due to high burying costs. Government targets of 100% renewable energy by 2020 aims to minimise projected impact costs from 1-2 centralised power stations on flood plains and high dependency on diesel fuel being shipped, ($3,000,000 per year). However, solar panels face unknown impact costs from cyclone/gale force winds and sea surge pressure and still rely on fuel. One electricity interviewee indicated past impact costs:

> "*We keep a lot of cyclone stock sufficient to bring services online. With a warning, everyone is on standby. No one can take leave; we aim to prepare ourselves. If a cyclone happened tomorrow, we have stock, power, 3 months' worth fuel storage, a full-time cyclone committee and our systems have been upgraded to better respond."*

Respondent LXIII notes significant fuel consumption volumes from 25,000,000 litres fuel 2013 to 28-30,000,000 in 2017 for 2 suppliers (1/3 aviation; 1/3 power and 1/3 road fuel) creates high impact costs for a single pipeline, port and shipping service supplier, if any event manifested. Many more will be affected by disruptions to economic activity (hotels, airport, transport links) given outer island shipping stockpiles only are replenished every 1-3 months under normal conditions.

> "*There is a fortune invested in renewable energy; yet power source depends on diesel. Energy empowers life but people don't see the supply chain that provides and depends on it, they do not appreciate it. People should want to save their utilities and marine ecosystem; having lived with drastic changes in tropical rain and weather for ages."*

Respondent 87 (*Utilities): "Devastation has increased to a point of no recovery." "Tropical cyclones continue to damage most Cook Islands infrastructure. Harbours, Airports, Roads, Water and Power are affected for most events, every time a direct hit occurs." "Storm surge lasts 5 days, cyclones hit two weeks. A drought prevailed for 6 months".* Respondent 8 indicates logistics assets took 14 days to recover on average. Roads and bridges failed on average once every 5 years, affected by other transport connections and safety issues. Respondent 91 (Roads/Logistics): *"The 2005 cyclones disrupted many projects and programs as the focus was on cyclone response and rehabilitation. The 2010 Cyclone Pat has resulted in a drive to review and update the current Cook Islands Building Code."* Engineers indicated how extensively damage could affect interconnected supply chain infrastructure and businesses, increasing time, resource and other opportunity costs with sanitation/water supply within a month, roads 2-3 months and buildings up to a year to reconstruct.

6.4.12: Impact Costs to Information/Communication Service Providers

Quantifying true impact costs of climate change to information/communication is challenged by the uncertainty of stakeholder physical and psychological reactions and access to sources. The more physical assets are protected, the more they retain the capacity to pre-empt successive costs by preparing stakeholders to minimise damage, response, recovery and other Figure 6.1 event phase, costs. Stakeholders depend on information and communication to monitor risks, minimise impact costs and adapt. This is compromised by physical, environmental and other impact costs to telecommunications. In 1997 Manihiki lost early warning capacity with a destroyed weather station. A book on Cyclone Martin reminds stakeholders of the severe costs when it Manihiki was stranded for a week after losing its telecommunication station. In 2005 90% of phone networks were razed. Evacuation costs included 200 tourists stranded in Rarotonga airport without flights, lacking communication from official sources.

In 2010 80-90% of landlines were shattered. Mobile, TV and radio transmitter reception disturbed communications for 3 weeks. Respondent 7 emphasised why single risk events such as cyclones were of concern, as several climate incidents have affected telecommunication equipment and connectivity:

"*On Manihiki during Cyclone Sally (1987), the satellite dish was picked up by the waves and thrown over the reef into the sea, and the telecommunications station which was constructed of concrete blocks, was completely destroyed and all that remained was the concrete pad. During Cyclone Pam on Aitutaki, the telecommunications tower was blown over and needed to be repaired in order for internet connection and general communications to be resumed".*

Blue Sky Pacific's fibre, cable, mobile and telephone services, switches, exchanges, satellite antennae and masts were ruined. *"On Aitutaki repair costs took a couple of days. On Manihiki, it was months of* *rebuilding and getting new equipment out."* The stakeholder expressed concern about providing numerical cost estimates for disasters, providing insight as to why stakeholders answered these questions the least, stating they were beyond her scope:

> *"…and I suspect for many people you may interview … I would suggest that you put these specialist questions at the end of the survey, because they will only affect a small number of participants. You have other questions ordinary business owners can still answer later on in the survey, but participants might not go past this section thinking they have done all they can."*

Respondent 9 considers the media are not physically vulnerable to revenue loss, although familiar but can respond within hours. They cautioned when a cyclone hits, even if the personal cost may not be too high, the cost to infrastructure and assets is significant. The media often had more awareness of specific impacts, with greater experience than recently established business operators or reshuffled/employed government sector interviewees. Blue Sky Pacific recently experienced a bushfire to its 2 main stations which affected satellite/phone/TV/radio reception for 2 weeks during this field research. This proved expensive to revenue and communication costs with no mobile data for visitors and locals. Cashflow is highly reliant on tourists. Respondent 36 notes communication needs and costs increase for most stakeholders during events. When asked about projected climate change impacts for information/communication services, he responded: "*A boat every 3-6 months makes essential parts and services even more vital, even now it presents an expensive exercise."* "*We have yet to experience a category 5 – experience is limited. The best we can do is to try and maintain services to the best. We do keep some spare parts on hand some here and most isolated islands keep basic minimum spare parts."* Remote outer islands services have been extensively damaged in past risk events, with infrequent transport services prompting massive disruptions during restoration.

Respondent XXXI echoes official responses, aiming to minimise impact costs for emissions mitigation rather than adaptation. Respondent 52 considers early warning systems and regular communication updates as essential tasks during a potential risk. The Cook Islands is well aware of historic risks for Rarotonga, if not the outer islands, with data and monitoring stations since 1997. 1889 Rarotonga rainfall records started temperature and other data since 1922. 10 staff working 24/7 monitor climate risks as they emerge to inform other MSC participants *"We are also involved CCCI with statements and IPCC. We aim to ensure the safety of clients as much as reasonably possible."* Climate Change Cook Islands, Emergency Management Cook Islands, the Meteorological Service, media and telecommunications sectors frequently coordinate and cooperate to publicise impending disasters, to curtail costs. They enlighten those abroad as to existing climate change effects. During an event, they have legally mandated responsibilities to provide Cook Islands disaster awareness, information and early warning systems. They monitor on a 36-hour alert for cyclones, investigating full formation for the full 3-5-day average lifespan and a month afterward. Critical staff are well trained, face overtime pay and a general call out, mobilisation broadcast on TV, radio and social media. Although the site appears extremely vulnerable to SLR; the respondent assured the observatory had been carefully evaluated as the best position and has survived since 1967. There is a dual seawall and vegetation, so even if big boulders destroy the first wall, the second remains.

EMCI lacks access to historic disaster impact costs being only formed in 2005 with legislation concentrating on all disasters, replacing the 1973 Hurricane Safety Act. The consultants responsible for reconstruction and recovery refused to provide the information. Inexperience led to delayed responses in information sharing and stakeholder consultation in 2010. "*A lot of things depend on people's actions and whether they feel we can stop/reduce/delay climate change's full impact." "You can't stop a cyclone but you can minimise the impact."* They usually send a cyclone warning notice at beginning of season to certain stakeholders but did not this year. They recognise ignorance of past impact costs has prompted careless developments including building on floodplains, vulnerable to cyclone and other events. They challenge stakeholders to consider *"If the sea will always remain healthy and whether there will always be enough fish."* This awareness targets consumers, producers and communities, but the information/communication sector still insufficiently coordinates marine tourism operators and their visitors, undermining mitigation, impact and adaptation efforts by local and Pacific stakeholders.

6.4.13: Impact Costs to Marine Tourism, Marketing and Administration

In 2016 marine tourism contributed 62.5% to GDP and is the most economically significant MSC stage. However, few resorts have directly survived a catastrophic risk or are sufficiently motivated and aware to favour adaptation. Even with 5 cyclones in 2005, only 5% directly closed. Sunset Resort, Vaima's and Trader Jacks were overwhelmed by 5 cyclones, waves 5-10m high. Occupancy dropped to only 60%. With more rooms risk multiplies, yet businesses can recover quicker. Publicity even produced T-Shirts boasting about surviving. Several retailers, marketing companies and government departments were impaired. Fresh produce and imports were restricted. Coral reef damage, rough sea swells and turbulence cancelled watersports and lagoon tours, and coastal erosion discouraged coastal tourism activities. Stakeholders express concern over lagoon algae on reef and in species migration changes affecting game fishing and whale watching. A few including lagoon cruise operators (Respondent 2) could not identify specific risks or impact costs for marine tourism, despite willing cooperation. They thought it difficult to recall how often each asset failed. "*Which assets are likely to fail? This is the big unknown. It's* *hard to answer for factors affecting vulnerability of assets."* Many remain complacent of others' impact costs. Respondent 28 commented that people come to fish and eat sea food, which their largest sales:

> *"As soon as it starts impacting on that – then we are worried about sustainability. Currently, we haven't really noticed any changes in fish volumes, quality or availability, all are pretty good. If anything happens, just pull boats of the water and store them inland. Just move back and continue business as usual so the fishing industry will not really be affected. Long liners go to the lee of the island and hide."*

Others were more specific, indicating high concern with specific events including other storms and cyclone warnings, droughts (especially 1998 El Nino), vector-borne diseases trifecta 2009/2015 and fish shortages (various years including February 2016). Respondent 69 however felt unqualified to answer. He was affected by the 2005 cyclones Meena, Nancy, Olaf, Percy and Ray for over 60 days. *"The entire building was affected – especially decks, landscaping, roof and windows and menu items."* Yet his coastal property cannot obtain sea, flooding or cyclone insurance. El Nino/La Nina changed fish availability, affecting business profits:

> *"This means wind velocity, wave energy and sea level rise are all issues. Similarly, if the reef buffer zone is further degraded by ocean acidification and beach sand replenishment is an issue threatening our land area and business infrastructure. Precipitation changes are also important because the food service industry requires a lot of water for hygiene standards and relies on fresh produce productivity linked closely to rainfall patterns, temperature and humidity. With electricity generation costs being very high in the Cook Islands and caps on grid connected solar (no licences currently being issued); the need to consider air-conditioning for guest comfort is a cost concern out of reach at present."*

Tourism representatives rather than visitors, are concerned about anything threatening sustainable guest experiences. They value a pristine marine environment, basing their marketing strategy on its continued existence. They are conscious of past cyclones creating reputational, marketing and other undetermined impact costs. After 2010, it took 2-3 years for tourism to recover. Concerns included competing among Pacific nations for tourists. Any failing to prepare for climate change face diversion costs to those more resilient. Droughts threaten water supplies. Respondent XXXIII considers most domestic tourism operators would probably agree about climate change awareness and concern, although it remains dominated by less-aware expatriates, lacking historic familiarity. "*Any risk event of catastrophic proportion would devastate the community – there is no certainty. We would experience a downturn in tourism numbers as among the first to directly encounter global climate change locally. Given its long-term problems that stay with us – how as a business do we survive and prosper?"* Many Aitutaki businesses still have not been rebuilt, lacking access to finance after 2010. Stakeholders are estimated by the professional tourism council to need 6-8 months of financial reserves to survive. They are already considering how marketing must change, if environments and climates change. *"What's the message going to be? What's your value proposition going to be? Are we at the tipping point, behind it, past it? Where is tourism headed? Is it sustainable?*

They consider many do not understand personal implications or costs with a naïve view of risks and coral bleaching. Banks do not consider need for refinancing or recovery costs for smaller operators although larger ones possess international insurance. Respondent 39 opened shortly after 2005's cyclones with storm and sea surge insurance cover. She recalls:

> "*The calm edge of the eye before the onslaught – mangoes and coconuts off the trees; impossible to drive through it; debris hurled about and giant boulders transported across the road; a lot of reef blocked upon. Coral got smothered from swells with a prime cyclone concern of wind and sea surge danger."*

Wind and sea surge were integrated into design and operations with curved walls to deflect waves from rooms. It prompted an underground water tank with 2 weeks capacity. Recently they achieved 76% average room occupancy capacity and are targeting 80%. Increasing Cook Islands tourism numbers to over 150,000 rapidly accelerates evacuation and other prospective cost consequences for this MSC stage. Respondent 54 echoes future concerns for retaining business under altered conditions, to retain procuring sustainable, local fresh products when possible and concerns when local people have not experienced a cyclone since 2005/2010. This risks complacency over projected impact costs, even among more conscious Cook Islands stakeholders.

6.4.14: Impact Costs to Consumers

Whether as producers, consumers, employees or employers, each climate change risk affects disposable income and the capacity to sustain other supply chain stages, whether temporary or permanent. The economic capacity of communities determines recovery potential and the ability to maintain imports, retail, port, shipping, logistics, financial, tourism and other MSC sectors. Communities equally rely upon other sectors for employment and investment, avoiding aid and to preserve living standards/livelihoods. Cost estimates derive from a variety of sources including survey/interviews and unpublished sources, for all supply chain stages. 1987 Cyclone Sally's consumer impact costs included $3,876,000 (53% food, 15% housing, 6% transport and recreation). Rehabilitation/recovery cost $6,700,000 including $1,000,000 to business; $1,000,000 tourism. Agriculture $4,300,000 (90-100% crop damage – Nassau, Pukapuka, Mauke, Mitiaro, Atiu, Aitutaki – salt spray Rarotonga) affecting a 50% fall agricultural exports, disruption 9-12 months and 3 years' food security. 80% of Rarotonga buildings were damaged, In 1997 31 public buildings were damaged by Cyclone Martin, with 4 buildings remaining intact on Manihiki. Roads were obstructed by uprooted trees and debris, 368 were evacuated to Rarotonga. The power station faced structural damage and only one bulk fuel tank remained. Water supply was limited to 2 hours per night. The tourism handicraft industry encountered $50,000 production/marketing and village support $225,000. Community income was disrupted 6-12 months on average. Manihiki faced psychological, physical and other costs, its population falling from 680 to 250. 19 deaths caused intangible economic, community and other costs. Consumers decreased savings to refinance survival. There were also opportunity costs associated with aid donations including lagoon clean-up aid and a foreign maritime patrol craft for security. These insufficiently addressed losses of residential income based on stakeholder content analysis.

Consumers rely heavily on the presence of marine resources and ecosystems. Any risk to food security, agriculture and imports, pressurises fisheries and aquaculture further. In 2005, 2,194 were affected with 8 injuries. Significant relocation costs included 150 evacuated from Rarotonga, 100 Aitutaki 70 Nassau and 200 Pukapuka. 15 temporary shelters for the first cyclone were destroyed by the third. In 2010 78% of all Aitutaki homes were affected costing an estimated $13,700,000 direct impact, Table 6.10 provides average consumption costs for a 3-5 cyclone event, adjusted to 2017 prices. Table 6.11 distinguishes maritime commodity consumption costs to address this thesis's specific distinction between maritime rather than agricultural/land-based impact costs from climate change.

Table 6.10: Average All Consumers' Consumption Costs for a Risk Event

Annual Consumer Cost	**$**	**Cyclone Duration Cost $**
Total Food	45,279,800	620,271.23
Housing	35,343,300	484,154.79
Transport	22,692,300	310.853.42
Credit/Loans	9,221,100	126,316.44
Miscellaneous	16,888,500	231,349.32
Fuel/light	6,770.206	92.742.57
Repairs	2,445,500	33,493.15
Insurance	454,100	6,220.55
Furniture	1,421,500	19,472.66
Appliances	3,365,400	46,101.37
Telecommunications	4,596,100	62,960.27
Cellphone	$594,200	8,139.73
Email/IT	$ 308,600	4,227.59
Electricity	$5,179,400	70,950.88
Kerosene	$6,000	82.19
Gas	1,567,100	21,467.12
Total	149,369,670	1,735,207.29

Source: Author, based on Cook Islands Statistics Office 2011 and interview/survey estimates.

In 2005 communities experienced a 38ºC heatwave. 5 cyclones created $7,870,000 in repair costs. 150 were treated for psychological trauma. In Pukapuka 140/160 homes were destroyed, 70% from wind, 30% wave damage. Official impact costs frequently underestimate the true extent of opportunity costs incurred by excluding aid recovery or adaptation costs. For 2005 total aid included NZAID $1,160,000 ($200,000 Emergency Assistance $40,000 clean-up and $35,000 for New Zealand volunteers); AusAid $130,000; China $30,000 and EU 600,000 euros. French Polynesia donated 28 military and 2 desalinisation units producing 120,000 litres per day; ADRA Samoa offered 1 month's food supply. Red Cross gave food and emergency supplies. 2 private fishing boats donated time and logistics. WHO presented $5,000; OCHA $50,000; UNDP 1 staff assistant worth $50,000; FAO $200,000 for agriculture. Stakeholder content analysis considers significant impact costs for this stage. The traditional view is that during disasters government focuses on infrastructure, people and businesses look after themselves.

Table 6.11 Maritime Commodity Consumption Costs

Annual Consumer Cost	$	Cyclone Duration Cost $
Total Food	45,279,800	620,271.23
Tuna	1,212,600	13,610.96
Flying fish	28,100	364.93
Frozen/other	2,225,200	30,482.19
Tinned fish	698,500	9,568.49
Paua	228,000	3,123.29
Mussels	76,200	202.77
Octopus	94,600	1295.89
Crustaceans	130,300	1784.93
Seaweed	48,700	667.12
Kina	1000	13.70
Smoked fish	9,800	134.25
Snapper	33,900	464.38
Other shellfish	205,100	2809.51

Source: Author, based on Cook Islands Statistics Office 2011 and interview/survey estimates.

Island dwellers depend heavily on marine resources, especially given crops can take 1-4 years to recover from a single event. Given shipping, agriculture, outmigration, and formal sector employment constraints, Rarotonga and Aitutaki remain tourism focused. Outer Islands aim for self-sufficiency and a subsistence economy. Chartering a plane in a health emergency costs $20-30,000. Wholesaler Respondent 27 noticed concern with vegetation, species and shell loss for traditional crafts, used to supplement tourism income along, with wet and dry season changes. Respondent 86 epitomises costs not just to government during each event but multiple sectors for communities. They close the ministry and deploy staff to assist with recovery:

"Cyclones in 1986, 1997, and 2005 caused destruction of villages and loss of life. Telecommunications,

flights, shipping, vegetation and crop damage, displacement of locals, recovery of country, economic downturn in visitor numbers and a power outage were all affected for each risk event. Failure is quite often dependent on the severity of damage. We have Category 5 cyclones. In some cases, assets and operations took up to 2-3 years to recover. "

Respondent 48 considers current and future impact costs are more from drought threats to water, food and income security. However, costs are likely to remain until buildings/infrastructure are replaced: "*For most of the population the issue has been water more frequent than before, always having to repair tanks and moving slowly to replace tanks. Fishers say the tides are changing, which also adds a risk."* Respondent LXVIII considers drought brings benefits – when flower comes, mangoes grow higher rates on dry island sides; agricultural productivity temporarily increases as if anticipating forthcoming shortages and destruction. However, each event yields entire crop failure, substantially jeopardising alternatives to MSCs. Increased temperature already makes it difficult to grow sufficient food, further enhancing the significance of imports and logistics. Implications for plant growth, yields and nutrition remain concerning.

Respondent 96: indicated concern when stakeholders with limited assets lose harbour and interconnected infrastructure access. They are used to surviving without any boat for 4-6 weeks. Respondent 59 *"We cannot go in isolation*. *Those who live with climate change daily treat their environment, community and lifestyle with more respect*." Respondents were more emotional and unable to provide specific impact cost estimates of other sectors. Respondent 87 (Communities): *"The entire community is affected in addition to your 'business supply chains."* Respondent 95 (Community) "*Previous risk affected – Cyclones, Tsunami warnings. Everything was affected. Each asset failed 60% of the time. People, communities, power, water, food supply*." In Aitutaki entire communities and MSCs still have not recovered after years, indicating climate change's indirect and intangible costs persist far beyond a few days, months or year. Stakeholders remain susceptible to the responses and extent of risk of other sectors, far beyond official reports and aid assistance, conditional survival based on government, the financial/insurance sector, communities and themselves.

6.4.15: Impact Costs to Financial/Insurance Sector

Whilst Chapter 5 established the financial/insurance sector as most unaware, unprepared and vulnerable to climate change risks; all other stages remain dependent on its willingness and capacity to minimise the extent of impact, adaptation and recovery costs. The greater the impact costs, the more stakeholders require the capacity to restore their businesses, production and consumption. This sector equally relies on stakeholders favouring proactive risk management, continuity planning and awareness to reduce liabilities, insolvency, operational and liquidity risks. However, repeated stakeholder claims during events has historically granted immense impact costs. For Cyclone Sally 1987, Cook Islands insurance claims exceeded NZ$4,000,000. Only 13% had insurance coverage, leaving 87% relying on meagre resources of government and NGO's. In 1997 an entire island experienced no financial sector assistance despite 75% residential buildings destroyed - marine resources, three cargo/one storage sheds, fuel depot, jetty, reef, wells, telecommunication, hanger, water tank, garage, workshop, terminal, two stores and power station.

After five 2005 cyclones, personal insurance impact costs were $4,800,000; commercial $15,033,000 and residential $8,200,000. However, remittances from concerned overseas Cook Islanders offered $51,068. Government offered $10,000 housing loans at 3-4% interest rates to residents, as the financial sector were unwilling to assist those with damaged collateral. Indirect impact costs included increased debt as aid/foreign loans increased from 7.3% GDP to 9.2%. Business investment declined from 12% to 9% of GDP as an unexpected consequence. In 2000 77 foreign businesses registered. In 2005 29 ($1,461,641) then 2006 11 ($1,025,060). Cyclone Pat created an immediate deposit decrease of 25.2%, then 5.9% as Table 6.12 illustrates. Loans to refinance immediate recovery needs increased by 30.6% in the aftermath, although limited to $10,000, despite impact sizes.

Table 6.12: Specific Financial Impact Costs for Cyclone Pat

NZ $	Deposits	Credit	Loans
2009	248,500	292,700	117,800
2010	185,700	285,800	153,900
2011	237,900	265,900	111,700
2012	233,800	247,900	106,600
2013	178,800	249,000	139,300

Source: Author, based on Cook Islands Statistics Office 2016 and interview/survey estimates.

Stakeholder content analysis previously noted local sector autonomy to determine financial products or services Respondents 3/4 note the main Financial Supervisory Commission requirement is for banks to have basic capital reserves for normal operations, a generic business continuity plan and a remote site to restore operations timeously, to reduce disruptions to supply chain, financial activity. Only two insurers exist. They are less exposed than resorts and foreign asset companies, as they limit cover to content and fire insurance. Nor do any banks provide sea surge, cyclone, flood and other insurance cover for the most probable risks occurring. Respondent 66 considered the Cook Islands are vulnerable to events:

> "*The physical impacts will affect providers and users of financial services in our jurisdiction". "Physical business assets had to be secured however none were damaged in the events occurring in our existence."*

Respondents XLIII/XLIV indicated banks target restoring operations from a temporary location within 48 hours, as historically situated on the main waterfront boulevard.

Climate change has impacted credit, loans and business but companies could not provide specific impact costs. International services remain vulnerable to telecommunication network loss, although stakeholders become more aware. It indicates the challenge of looking into a climate change future. *"We are lucky a cyclone hasn't really affected the banking community –hoping to have proper guidance, a plan and resources when it does. No armed forces exist. People remain dependent on each other as a community or vulnerable to external aid and assistance" (*Respondent XLIX). The sector perceives itself as not informed on risks and impacts. It noted cashflow interruptions. The local bank has offered a grace period. "*A ship will affect retail and consumer prices. Government can only do so much for any disruption. Many clients have cottage type businesses – depend on tourists for ability to operate could affect credit, liability, operations."* In past events, the locally owned bank offered moratorium to allow stakeholders to remain in business although it currently lacks visibility. Respondent III noted a lack of credit access to aid recovery and explained the impact:

> "*Outer islands boats cannot go out, mooring outside on reef and transfer out. Shipments have been affected. All these new wharfs and still the ships cannot go in apart from Penrhyn. In Rarotonga only certain times could they enter, offload and leave –boat would have to stay out of the port. We don't have ground support staff service as in other countries, government can deploy whilst appealing for aid."*

Ultimately, entire supply chains require the financial/insurance sector after a risk event targeting specific impact costs. However, cross-sector damage cascades across multiple participants, extending to the entire Pacific MSC and others.

6.4.16: Results: Factors Affecting Magnitudes of Impact Costs

Analysis of surveys and interviews showed the following key factors influenced the extent of climate change, impact cost magnitudes for a Cook Islands MSC. Impact costs were measured and analysed to reduce vulnerability, increase resilience and minimise disruption/externality costs. They help stakeholders to identify and exploit opportunities and avoid worse fates. It aids to ascertain the liability or responsibility for risk event impact costs. Measuring costs also determines where costs develop and multiply, to avoid greater risk exposure. Future research could analyse consequences for development, economic growth, externality costs, supply chain performance, productivity, stakeholder requirements, survival, reputation, ecosystem, key objectives and critical cost thresholds. Survey and interview participants consistently referred to cost, time, vulnerability, resilience; Asset Design/Service life, Stakeholder Expectations, Will/Inaction and Asset/System Interdependence as key disruption factors affecting impact costs. Cost magnitudes were further influenced by geographical location, risk type, size, duration and intensity. Content analysis clarified the following factors influenced how persistent costs were for climate change and whether stakeholders recovered.

Factors to Ascertain Extent of Impact Costs

- Complacency/inaction/ risk ignorance.
- Conditional probability of an asset failure.
- Existing priority on government not aiding private sector awareness, resilience, recovery, survival.
- Failures to resolve other challenges/environmental pressures.
- Insurance type.
- Just-in-time production, global source procurement.
- Lack of foreign supply chain stakeholder interest/willingness/action.
- Location – vulnerability, resilience.
- Outer island accessibility and distance.
- Presuming business as usual, lack of reserves, ignoring research, delayed decision costs.
- Relationship including mistrust or a lack of coordination.
- Reliance, initiative.

Factors Affecting Stakeholder Successful Survival/Recovery Content Analysis

- Adaptation.
- Adapting to opportunity not business as usual recovery.
- Competitors versus collaboration –impact costs of competitors versus own.
- Ecosystem protection.
- Extent of aid/reserves/support/flexibility.
- Extent of organisational loss, reputation, relocation costs.
- Extent to which businesses/stakeholders have experience, overcome past-existing impacts.
- Event specific impacts/location.
- Insurance.
- Local autonomy/initiative rather than international centralised control.
- Local sourcing, rerouting/contingency plans; collaboration and joint resource pooling.
- Observing events, sharing information.
- Price, volume, cost, quality, demand, supply, local and foreign market conditions, affected supply chain stages.
- Product substitutability/necessity.
- Supply chain partner and network responses.

6.5. SUMMARY:

With access to risk event and impact cost data, stakeholders can partially forecast future climate change, impact costs for MSCs as direct costs over the event periods in Figure 6.1. This considers how impact cost magnitudes will change, providing a mechanism for stakeholders to flexibly calculate estimates using non-traditional sources. Assumptions follow those summarised in Chapter 3 and section 6.2. This improves top-down approach flaws, reducing data precision and model misspecification error via standardised data. It simultaneously considers an event's probability of occurrence, duration, frequency and intensity, risk resilience and vulnerability. This could be applied to sensitivity analysis, revised to include site specific factors, uncertainty over future emissions levels, depopulation trends, demographics; climate sensitivity and response. Additionally, ignoring other stakeholder actions or inaction; could accelerate joint vulnerability and impacts, given asset interdependence and mutual functional reliance.

6.5.1 From the Cook Islands to the Pacific Region to Global MSCs and Beyond.

The vulnerability of Pacific Island states and the significant financial resources necessary to adapt, is evidenced by the Cook Islands requiring a minimum 33 times higher than their entire GDP ($**139,189,956,520 (33.5 x 2015 GDP)**, at current undiscounted value. This is based on summarising each stage's specific impact costs. This section considers how these future impact costs may diverge under various IPCC scenarios, time horizons and risk types. Impact costs are climate change scenario specific. This emphasizes the need to consider multiple parameters when adapting. B1, A1B, B2 scenarios. Given the inaccuracy of previous climate change, aggregate cost estimates, the impact cost estimates above could be calculated as information is updated for 2015, 2030, 2055 and 2090 time horizons. The challenge consists of how to adjust historic data to future risk events/time periods and present. Although climate change uncertainty prevents accurate forecasting of proper future costs, these conditions are included to provide a generic approximation to stakeholders. The number of currently vulnerable stakeholders is summarised in Table 6.13.

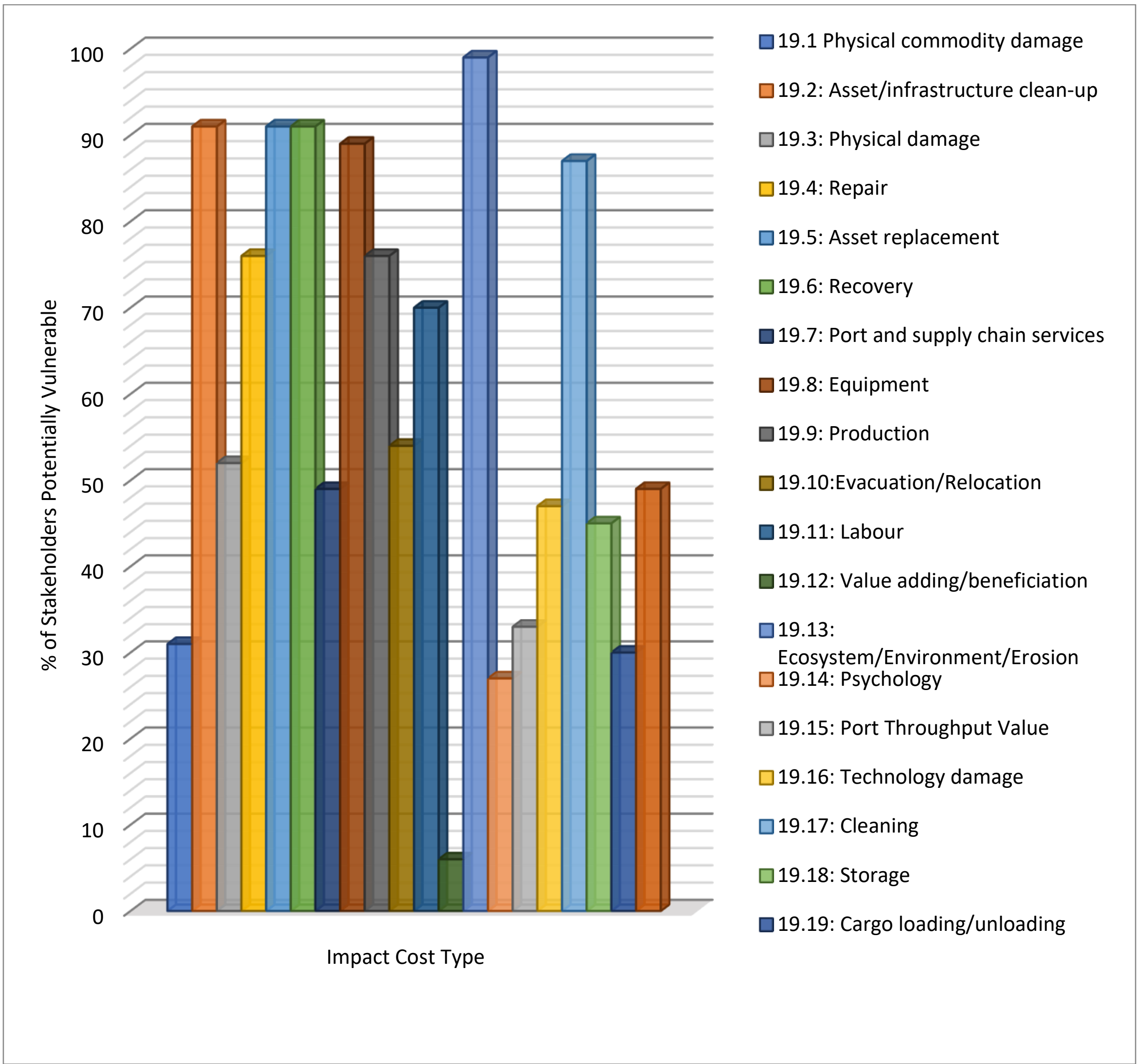
Table 6.13: Total Number of Existing Stakeholders Vulnerable to Future Impact Costs

MSC Stage	Total Population
Ecosystem	1894 species
Producer	1971
Beneficiation	72
Seaport/Terminal	167
Shipping	247 direct, 559 indirect
Roads/Transport/Logistics	39
Customs	10
Wholesaler/Retailer	414
Fuel/Utilities	7
Information/Communication	27 direct, 11,000 mobile, 7700 landlines
Marine tourism, Marketing/Administration	257, 7 marketing, 24 administration
Consumer	14974
Financial/insurance sector	17 direct + unknown offshore/foreign
Total	19,237 direct, 11559+ indirect

Source: Author, based on Cook Islands Statistics Office 2016 and interview/survey estimates.

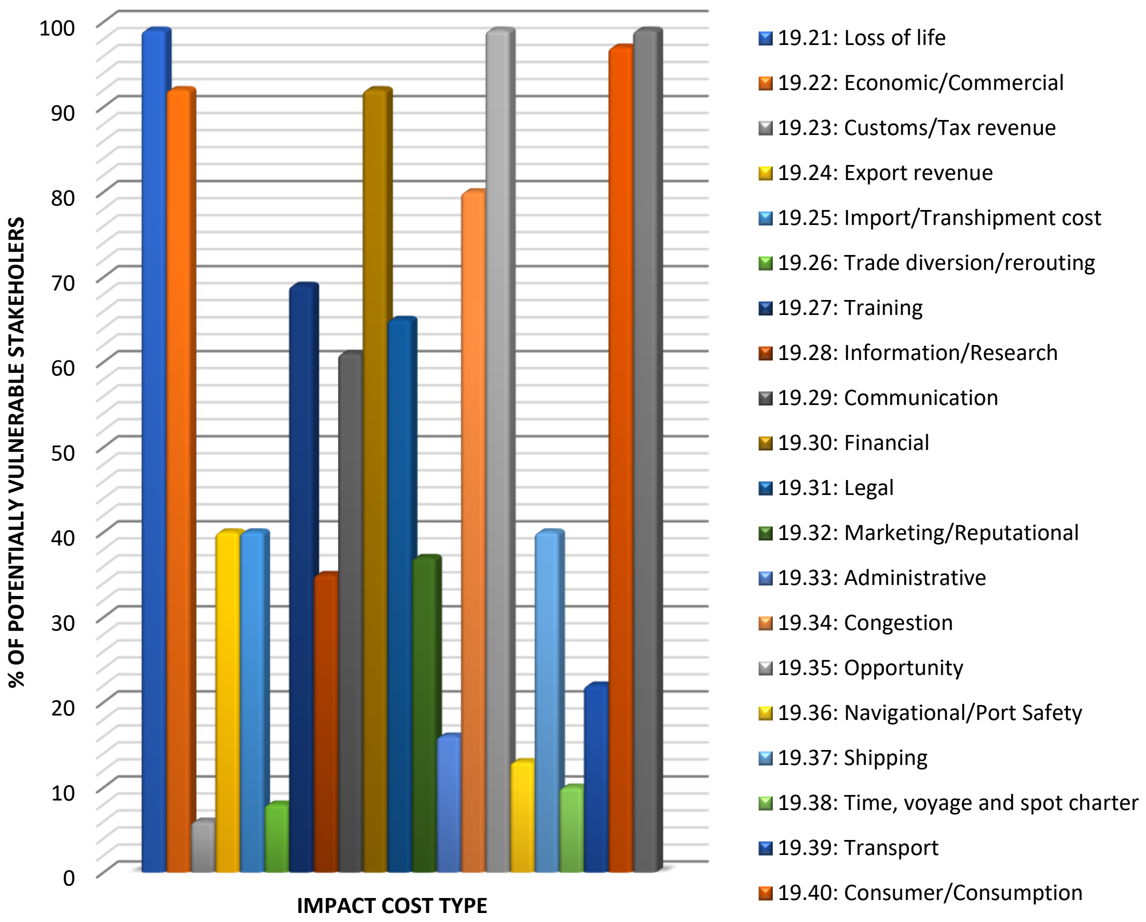
The proportion of MSC stakeholders for specific risk types is provided in Figures 6.9 and 6.10. Average costs can be substituted for data gaps of non-respondents in future research. Costs are conditional upon risk type including Storm, Flood, Bushfire, Cyclone, Drought, Gale, Heatwave, Landslide, Earthquake, Tsunami and Volcano. These assist stakeholders to more accurately gauge climate change. They could determine whether impact costs affect risks, occurrence probability and adaptation decisions and if these affect costs. It considers if awareness/resources changes impact cost size. It can investigate if resolving constraints to adaptation or adaptation actually minimise existing or future costs.

Figure 6.9 Future Climate Change Impact Cost Types to MSC Stakeholders.



Source: Author, based on Cook Islands Statistics Office 2011 and interview/survey estimates.

Figure 6.10: Additional Future Climate Change Impact Cost Types to MSC Stakeholders.



Source: Author, based on interview/survey estimates.

Climate change adversely affects not just the Cook Islands MSCs but other Pacific supply chains. An existing port-centred approach to climate change and risk management ignores competitor benefit, costs and interdependent participants. Impact costs are not just local but global for a single event. They expand beyond resource security/opportunity cost, maladaptation, collapsing ecosystems, and physical asset disappearance. Existing approaches ignore the value of local stakeholder consultation and data along with changes to future trade patterns as psychological, economic and physical responses to impact costs. Whilst this research targets the Cook Islands, impact costs extend to similarly exposed assets, businesses and stakeholders across the South Pacific and globally for all those directly/indirectly affected by the supply chain. The Cook Islands has 559 registered shipping vessels but 540 primarily use it as a flag of convenience and never visit. Over 150 offshore companies utilise it as a tax haven. In 2017 14,301 tourists visited. 77% imports came from New Zealand ($84,000,000), 9.99% Fiji ($6,000,000), and 5.3% ($2,000,000) Australia. Most pearl exports affect Japan, fisheries the USA, Spain and China whose vessels frequent the EEZ. Once all scenarios, assets, costs, risk types, stakeholders and stages are factored in, impact costs are projected to be far more than mere disruptions to a single Cook Islands, MSC and economy.

This chapter shows the maritime sector's economic significance to the Cook Islands. As an example, the findings illustrate the cost of cyclones/Black Swan events. Neither 'gradual' costs nor the impact costs of inaction/opportunity or disruption are minor. The analysis also indicates how quickly stakeholders respond and disruptions are recognised/addressed. Many impact costs are reducible with effort/concentration but not yet estimated or adapted. This chapter provides estimates to determine how expensive projected increases in risk event probability, frequency, duration and impact/intensity can be for stakeholders. The Pacific presents an example of existing risks, to prepare others for low probability, high impact events. Without data or existing data limits, stakeholders cannot understand or realise certain impact costs are generic. Others are risk-specific, regardless of factors affecting impact cost magnitudes. This simplifies identification, calculation and responses in answering impact costs. Stakeholders will not be able to pinpoint cross-sectoral, stage or system impacts. They will need to consider not just existing output/costs but future design/optimality.

Due to limited awareness of climate change risk events and associated impact consequences for MSC stakeholders; they would not be able to evaluate and understand the extent of climate change impacts. They underestimate risks and remain unprepared to mitigate, adapt and exploit opportunities. This exposes them to more MSC disruption, as demonstrated in Chapter 5, and the risk-vulnerability tree in Figure 3.2. This emphasises the framework's value to improve understanding of the identifying factors responsible. Stakeholders perceive governments will respond and aid agencies will provide, abdicating personal interest and responsibility. They become neither physically nor psychologically prepared, failing to prioritise either long or short-term adaptation. The findings from the Cook Islands MSC case study aim to overcome/reduce inaction, apathy, indecision, delays, maladaptation and opportunity costs. By mainstreaming climate change via climateproofing, this case study encourages stakeholders to reduce existing climate/environmental pressures wherever possible. It endorses valuing ecosystems for MSC continued existence/prosperity. This creates a more efficient resource allocation to minimise impact/reduce recovery barriers and increase subsistence. Concerned stakeholders can assess more comprehensive personal implications of climate change and whether or not they are sufficiently prepared.

CHAPTER 7: CLIMATEPROOFING A PACIFIC AND GLOBAL MARITIME SUPPLY CHAIN'S FUTURE: THE COOK ISLANDS

7.1: INTRODUCTION

With increasing globalisation marine ecological resources and economic activity are being disrupted. Chapters 5 and 6 have shown global stakeholders must acknowledge climate change risks as a serious threat to supply chain survival and prosperity. This chapter investigates how they can prepare to survive catastrophic events with minimal disruption risk to fulfil an IPCC, 'business-as-usual' scenario. The Cook Islands and other Pacific locations are acclimatised with decades of adaptive experience. This chapter discusses how this region can learn and benefit from their experience in dealing with climate change events. It utilises descriptive content analysis. To answer ARQII, section 7.2 identifies existing constraints to climate change adaptation from interviews and surveys

To address KRQC/ARQI, section 7.3 evaluates existing Cook Islands' adaptation solutions. This assists stakeholders to climateproof a Pacific and global maritime supply chain's (MSC) future. Section 7.4 presents thesis results from specific stakeholders' perspectives. These can be combined to form comprehensive strategies for other present and future supply chains in section 7.5. Climateproofing supply chains focuses on systematic adaptation. This enhances resilience, reduces vulnerability and promotes opportunities in section 7.6, seeking to reduce maladaptation and opportunity cost, through providing critical evaluations of existing policies and solutions, mainstreaming climate change risks as a core priority. Stakeholders with finite resources can then target the most effective adaptation measures. Appendix XII summarises other Pacific nations' adaptation strategies. These aim to assist stakeholders in dealing with constraints, minimise disruption costs, ensure optimal resource allocation and promote more effective decision making and investments.

7.2: STAKEHOLDER CONSTRAINTS TO CLIMATE CHANGE ADAPTATION

7.2.1: The Cook Islands

The constraints to climate change adaptation for Cook Island MSC stakeholders are covered in survey questions B1 and B7. These provided a 100% response rate for 99 stakeholders and are summarised in Figure 7.1. Whilst no single constraint dominated across stages, 63 respondents considered uncertain information and need for accurate, effective research as the most significant (12% of total). 54 respondents perceived psychological reactions (11%) and 51 geophysical/environmental limits (10%), as the next major reasons why stakeholders have not adapted, despite acute risk-perception awareness and impact costs. Conversely the least significant constraints were commercial fixed costs, and planning/zoning with 2% of identified total constraints. This enables researchers, policy makers and businesses to identify which constraints exist, which can be resolved through research and investment and which can be prioritised. It possesses direct stakeholder consultation and field research advantages rather than externally imposed solutions. Commercial implications of not resolving these constraints include increased impact costs, higher risk and adverse MSC performance, cargo quality, speed, security and other stakeholder requirements as previously verified. Stakeholder content analysis provides specific insight into individual and stage, constraints to climate change adaptation in subsequent sections.

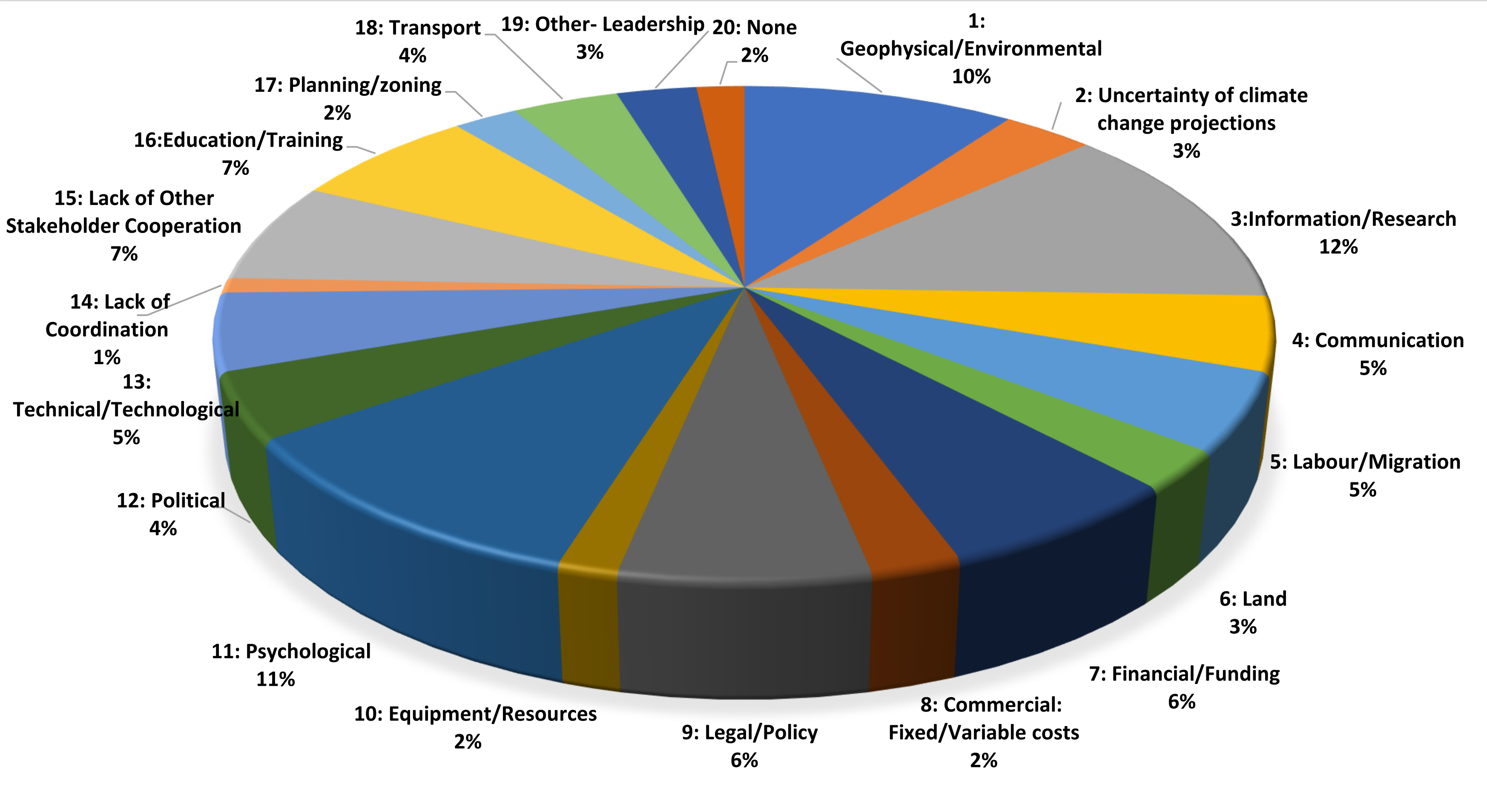
7.2.2: The Transferability of the Cook Islands Study to the Pacific/Global Region.

Cook Islands' constraints are also experienced by other Pacific and MSC stakeholders. One stakeholder concern was the risk of over-information and exposure. The port, government departments and communities often indicated aversion to participation as questions were similar, especially over climate change awareness. Aid agencies and researchers appear not to consult previous climate change research. For funding, Fiji, Samoa and Cook Islands stakeholders reported delays over access and resource allocation, lack of professional staff and unwillingness to listen to stakeholder priorities or incorporate other supply chain stages. Interview questions 8 and 9 were included to identify the extent of stakeholder information sharing and cooperation in Figure 7.2. These highlight constraints experienced regarding land, environment, transport, labour and formal infrastructure/assets. They emphasise numerous adaptation challenges, when combined with the extent of impact costs, number of stages and stakeholders which could be multiplied across 17 Pacific nations. Providing qualitative content analysis via specific insight, can assist in resolving these constraints globally.

Respondent 50 noted information is constraining effective mitigation and adaptation. "*We need to know what is happening around us. We need to know emissions produced per EEZ, before we can consider the impact and plan to adapt.".* In relation to this, reviewing past research is deemed imperative to avoid maladaptation and opportunity costs. Determining the sustainability of fisheries, tourism, underwater mining and aquaculture would determine the feasibility of the Cook Islands and other Pacific nations. Knowing how to calculate this and the data required is important. He raised a need for data: *"Do we know our carrying capacity? Does the normal Cook Islander contribute to climate change and how? Do we have activities that contribute to climate change and how? How do imports affect emissions increases?"*

When asked if information would help to change behaviour*: "People need awareness of benefits. It will take some time. It won't change overnight."* Respondent 52 mentions the importance of accurate early warning systems, cooperation, technology, data and sufficient labour to operate 24/7 to overcome these Pacific constraints. The Cook Islands lacks recent experience in contrast to regional neighbours. Equipment, training and psychological reluctance remain similar across the Pacific. Trends need to be determined using evidence to convince of the reality of climate change. Migration remains a regional concern, diverting future resources and capacity. As commented by one respondent: *"It's a concern. But some people would still like to be a part of this Paradise".* He suggested making input into international forums which would promote transferability to other nations. Respondent 58 cautions challenges in halting migration, given many leave from climate change uncertainty, reduced outer-island economic prospects and loan-defaulting. Land, water and resource scarcity reinforces this. Training is another impediment as few potential professionals exist and few are willing to adapt even when paid, concerned with missing home. "*A lot of people do not take calculated risks. Most people are scared to make mistakes. If no one has the knowledge, drive and vision to carry it out, it otherwise just remains a written thing, someone's dream."*

Figure 7.1: MSC Stakeholder Constraints to Climate Change Adaptation



Source: Author

Figure 7.2: Pacific MSC Constraints to Climateproofing Adaptation.

Source: Author.

7.2.3: Marine Resources and Ecosystems

Respondents 19 and 20 strive for marine ecosystem rehabilitation but are concerned about uncertain climate change, limits to technology, natural engineering and psychological will to reduce impacts. They feel limited in their options, e.g. physical elevation, replant vegetation, artificial islands or migrate.

> *“We need to be realistic. Perhaps use experience to see what we can do to futureproof the Cook Islands. Otherwise you might have to say to the developed world: ‘If you value your pearls so much, resources, your fish in everything else; you might need to invest in it.’ It all starts with who you are as an individual.”*

Many places are data-deficient, reducing continuous risk monitoring and assessment. The Ministry of Marine Resources have insufficient resources to undertake things such as genetic sampling tests or identifying keystone species to preserve. One mentions disparity in communication and cooperation between official experts and communities. *“You can’t make the change until you see the change.”*

7.2.4: Producers

Respondent 9's prime concerns include high logistics costs and attracting foreign investment, anticipated to worsen with climate change. Foreign fuel and catch cannot be sold to locals. Offloaded catch is processed for export not domestic consumption. Domestic commercial fish prices remain high and scarce. Bait has to be imported from Asia. The Cook Islands have the highest fish licensing fees in the Pacific. Yet sufficient demand exists, which may aid in financing ecosystem rehabilitation including the Marae Moana, marine sanctuary. "*Nothing like the real thing to prove it."* Respondent 47 indicates marine ecosystem constraints, climate change uncertainty, and stakeholder reactions will determine the extent of successful Pacific producer adaptation to fluctuating fisheries. Global population increases are placing further pressures on marine resources to enforce sustainable practises, with finite capacity. Participants indicate historical data is not reliably available before 2013, complicating the capability to specifically monitor shifting marine resource conditions and attribute fisheries yield declines, to climate change. Intriguingly, finance was unmentioned as a constraint compared to numerous other stakeholders, but leadership was. *"There's a lot of money floating around. However, it's difficult getting good people who are passionate and leaders to support and manage it, seeing the return of managing marine resources."*

7.2.5: Marine Beneficiation and Aquaculture

Respondent 8 echoes the prime marine industry and aquaculture issue is the lack of effective institutional capacity, will and leadership over climate change for the pearl industry. Respondents feel the Pearl Authority lacks involvement in ecological rehabilitation and gives insufficient assistance to farms to adapt., It has only 4 staff members and was unwilling to participate. It lacks powers to enforce regulations and protect consumers. Stakeholders indicated an unwillingness to coordinate, cooperate, communicate and share information with unresponsive leadership, acting in isolation. Local farmers are reluctant to share sizes, volumes, environment; technology management and other practises, although individually concerned and adapting. This limits the potency of systematic supply chain adaptation

Aquaculture faces several constraints to capable adaptation including high fixed costs. Revenue side has been low and too stable over the last three years. 90% of farmers survive by moving up value chain or supplementing income rather than full time production. Significant uncertainty exists for future survival in adapting marine ecological conditions to increasing ocean acidification, SST, species migration and other risks. "*We have been hampered by this narrowing period working to six months."* Production has decreased from over 400,000 to 10,000 pearls. They express concern with the Pearl Authority's unclear leadership, marketing few pearls overseas and not promoting industrial growth. Another adaptation constraint is limited cooperation with marine tourism who have similar interests in marketing and preserving the Cook Islands as an eco-destination. Interviewees identified political and administrative interference in one New Zealand Aid project. The local council restricted access to $3,000,000 for pearl equipment. Bureaucracy gave farmers a month to produce a five-year business plan, jeopardising the aid. Farmers pleaded with the Commission directly but only half was distributed as Manihiki Island Council placed restrictions. Immigrant labour has been suggested, to reduce local constraints hindering adaptation and prosperity, but stakeholders expressed concern that no future population or resource policy had been considered, given emerging risks. Respondent 24 noticed *"Existing adaptation solutions are not as effective as we want them to be."* Respondent 30 commented *"The threat to my pearl business is real and urgent. Adaptation is definitely not going to be easy."*

Respondent 30 focuses on communication, cooperation and information sharing as an essential constraint to adapting pearl aquaculture and communities. "*Because of remote islands, it's difficult to replace things We have to look strategically, used to self-sufficiency."* To overcome this, she proposes effective lagoon management and active risk monitoring for individuals to recognise changing conditions and understand the need to act

> *"Stakeholders may not prioritise adaptation due to lack of knowledge and understanding. We all live in a community with different languages. We all experience different literacy levels. But sometimes the community can create barriers because they feel their authority is challenges or compromised. The language and tone matter, otherwise they take it as a threat."*

Stakeholders need to commit with action. However, they apparently are considered needing more responsibility and leadership. They often wait to rely on others, expect to be told and pass on responsibility. Certain interviewees felt obligated to demonstrate decisive leadership including a social media campaign and Facebook page to minimise disruption and remind communities.

Adaptation is demand not supply-driven. Most customers are not eco-conscious or concerned about climate risks, contrasting with farmers witnessing changes. However, pearl sector adaptation has been hindered due to political/administrative and other constraints where stakeholders feel insufficiently valued by government, NGO's and foreign investors. Farmers within the pearl industry are left mostly alone without forthcoming plans, guidance or future vision.

> *"We set ourselves to help farmers. It's our business, our investments. We are the experts; we've been doing it. We know producers. Some want business to survive and that's why we need scientists and support. No one wants to listen to the Association, seriously considering closing down."*

However, local council autonomy controls pearl permits and restrict access to donated aquaculture resources, causing bureaucratic delays to supply chains. Council decisions should help the pearl sector but they remain sceptical, doing their own marketing with limited success and resources. Stakeholders felt silenced, insufficiently consulted and ignored without transparency over funding distribution, aid or equipment. They were concerned about financial reporting standards and no follow-up on proposed and implemented projects. Respondent LX indicates the marine industry cooperates inadequately over credit, information, marketing or training. Participants need to fund sustainable achievements for all society, not just the pearl industry. MMR need proper coral inspections not just limited water quality control testing. Analysis affirms the Pearl Authority is available and has enough finance and equipment, but should be accessible and restructured with evidence of future vision, coordination, research, marketing promotion and technology. It can improve in finding markets, cooperating with tourism and others.

7.2.6: Ports

Avarua port's major constraints to adaptation are funding and physical limitations to climateproofing, although prepared up to 0.5 metres of SLR. Geophysical/environmental limits insufficiently protect coastal assets, interconnected infrastructure or vessels, requiring relocation based on Respondent 15 and others' views. Respondent 32 indicates labour is a significant constraint to risk reaction and adaptation, getting only a maximum 6 hours for the port, compromising capacity to operate: *"The severity of climate change is increasing. We have to move forward. We need to continuously look at options. When we see what will affect the port, we can decide what we can do to improve it, given financial straits. So it leaves something for us to rebuild it, not when something happens, nothing is left."*

The port office and shipping agency containers remain vulnerable if not evacuated in time. Respondent XVI for the port replied "*We must learn from each event that impacts us, compiling information of our experiences and reactions. For we have to adapt who we are and how we operate in order to move forward."* Producing locally-orientated solutions can motivate stakeholders from personal vulnerability, along with outlining consequences of ignoring recommended actions. For example, a ship blocking the narrow port channel would paralyse over 90% of the local supply chain/economy. Improving communication via sufficient information is needed to motivate people to act

7.2.7: Shipping

Respondent 13 identifies financial constraints for shipping and logistics operators prioritising climate-change adaptation with high fixed costs and limited profit margins for 6-12 vessels per year. If damage occurs, a New Zealand engineer costs at least $11,000 for 4 days (who advises expensive import replacements) rather than $700 for local equivalents and repair. Foreign fishing licenses were considered to accentuate climate change, with little benefit to local shipping and businesses. Locals gain 14 cents/kg, yet the market price is $20-$26. Respondent XIV expressed psychology as an action constraint. *Many people don't care about it.* "*We would lose life far more quickly and less painfully than surging climate change. After all we are collapsing our ecosystem anyway!"* Many people are not seen to be taking it seriously, requiring firm, decisive leadership. "*A lot don't want to believe it. It affects us all. We all have to be on this world, our one home, so why not work together? This is our life and future."*

Respondent XXXVIII noted shipping could reduce emissions by slow steaming. However, it is expensive, adding to costs, voyage frequency, cargo delays and disruption. It generates lower cargo volumes, requires higher speed to be cost-efficient, enhancing emissions and adaptation costs. Travel at optimal speed would be more effective. These remain potentially problematic given economies of scale, low unit costs, profit margins and high fixed costs encountered by many shippers along with global and local dependency. Avatiu harbour experiences physical constraints as one of the narrowest Pacific harbour channels, limiting climateproofing and expansion capacity. "*There is still no direct entrance protection, the seawall has failed and is entirely constructed of large boulders, which may fill the harbour up. The difficult question is what do you build for to prepare in time?"* The major constraint from shipping's perspective is consumers, producers and domestic economies do not support localism in products, food security and autarky to provide greater climate resilience from economic diversification. Many favour mitigation and adaptation for others reluctant to change consumption patterns and lifestyle.

Respondent LXVII (shipping company) echoes communication and other limitations when targeting awareness rather than actual action. She also noted possible business relationship-costs for droughts and other risks. *"One of New Zealand's biosecurity requirements is cleansing vessels and containers."* Participants presume the Cook Islands are more organised and prepared than many. They take it seriously, living through several cyclones and events over recent decades. They mention self-interest as a motivator for more efficient and sustainable shipping/trade/fuel/technology practises. However, they indicated more research would help, given insufficient data on risks for ports, shipping and supply chains, especially managing multiple users.

7.2.8: Customs

Ten customs staff are meant to operate 24/7, undertaking increasingly more with fewer resources. Customs registers labour constraints as the major barrier to adaptation. However, it can deploy other departments when needed. Challenges are keeping everybody satisfied with service delivery, especially during an event disruption, protecting the marine environment and ensuring sustainability. It notes psychological complacency among stakeholders, especially in reducing emissions/mitigation and waste management. "*The younger generation may lack awareness and exposure to climate change and natural disasters given time lags."* (Respondent 10). It backs up data but 40% of systems remain manual. It lacks technical people to operate X-Rays. Existing technology (2012) costs $300,000-400,000 per month but lacks integrated, single data entry capacity to modernise customs to new risks.

7.2.9: Logistics

One respondent identifies politics as the main challenge to implementing climateproofing or existing National Development Plan. Respondents 11 and 12 contend the most significant impediments to adapting outer islands economies to climate change are high fixed and transport costs:

> *The biggest issue is the lack of meaningful government support for private sector with no subsidy to offset fuel costs. There is a big gap between what government expects and does find. It presents a harsh reality to local voters given declining outer island migration and economy prospects."*

It gives people the chance to improve resilience and survive with markets for aquaculture, climate resilient harvests and cottage industries as a means of adaptation. Labour constraints impede economic revival and adaptation, especially to stimulate consumption demand and production capacity: *"Keep talking about it but not really doing it. Problem is we have a whole generation of Cook Islanders that left."* "*All nations need people to build a country."* Reliance on immigrants, where possible, is necessary, as the private sector struggles to operate, lacking viable domestic cargoes and needing local people to return to underwrite future investment.

7.2.10: Retail and Wholesalers

Respondent 1 identified businesses did not consider climate change due to insufficient training, funding constraints, and lack of priority from government or aid agencies, receiving nothing after catastrophes. They struggled to recover and several faced bankruptcies: "*We need to catch up very quickly. We need to bring climate change resilience and adaptation into business."* They identified businesses do not inter-cooperate, being highly competitive and individualistic, only interested in direct and immediate objectives. Current policy does not provide funding for climate change recovery or adaptation, only for new commercial opportunities. If government understood businesses' importance to communities, they might aid businesses to mainstream risk, remain sustainable and survive. Aid after a disaster needs to be commercially effective. Respondents 17 and 18 echo financial constraints, intensified by administrative barriers and limited training, even when willing to adapt:

> "*We need to change business practises to keep them from always relying permanently on government support. We have changed business practises to be more resilient. Their only solution is to prepare to go overseas. We are trying not to promote that. We are trying to overcome it. The resources are there. It's just hard to sustain it and keep remaining ones in business.*"

7.2.11: Utilities and Interconnected Infrastructure

Respondent 34 identified the absence of Cook Islands Infrastructure Technical Standards as a vital constraint to climateproofing utilities and other infrastructure. "*The best standards are still very general, not designed to ensure a set amount or given level of service.*" It also mentioned problems with consultants and aid agencies lack of local consultation, involvement and familiarity. Designs frequently ignore local climate conditions. ICI developed a herringbone design for seawalls to deflect storm surge, wind, currents and wave energy. It integrates climate change into every adaptation design, even if temporary. Aid projects also ignore local materials and economic activity opportunities, preferring to benefit their own country's export industry. Funding is highlighted as another constraint. Respondent 35 noted few engineers, limited formal urban planning, zoning and law enforcement as constraints, so revising the Building Code for the private sector to retrofit existing assets.

Respondent XLV identifies numerous constraints in targeting 100% renewable energy by 2020 for the utilities stage. These include determining implementation of new "disruptive" technology, land ownership constraints, finance and managing clients' psychological expectations*: It would be easier if we invested, cooperated, owned and managed everything ourselves from an operational perspective."* Stakeholders view impacts personally, rather than evaluating the supply chain holistically when prioritising. "*Everyone has a view on achieving 100% and their position on how when people have their own agenda that makes forward planning so difficult".* Professionals call for private sector cooperation and co-funding, given initially higher costs are projected and limited understanding. They use social media and marketing to convince communities of benefits of personally investing in renewable energy. They identify the expense of burying cables and technology limits in solar storage and transfer capacity.

Respondent 37 also indicates geophysical constraints to utilities and public-sector assets hinder relocation of core assets to higher grounds. (Crown land is mostly on coastal fringes and hilly inland). Maintenance is another expense for asset management plans, with only a small team, most work being outsourced to a few private contractors Local skilled labour is scarce and transport infrequent.

Coordination is complex, having to synchronise time logistics and project management. She mentions the challenge of ensuring buildings comply with the new fast-tracked Building Code. "*There is only so much you can do to bring it up to a certain standard. It all depends on the building/resources. It's expensive but necessary given the speed and frequency at which events are projected to occur".*

Cyclone Pat's extensive impacts indicate communication and coordination could have been improved. Core businesses and government stakeholders were unaware of detailed impact damage.
Respondent 37 scoffed, as did others, at whether more information really was a constraint to effective action: *"We know what we know. With enough information around to do a sufficient job; other than a crystal ball predicting the event, not sure you can ask for more."* Innovative outer islands people are coming up with short term solutions but need to convert them into more permanent measures. Respondent 53 suggests one constraint remains dependency on a single petroleum pipeline; given concerns of safety, commercial viability and marine environment and insufficient state support for a solution. Challenges remain in interpreting scientific information and climate data Access to meaningful, clear information is outlined as necessary Practical, affordable, tried and tested solutions are needed with technology that is sustainable.

7.2.12: Information and Communication

Respondent 7 observes the Cook Islands government ICT division does not focus on risks, policies and adaptation, but on maintenance and basic government support, due to lack of prioritisation, technical capacity, funding and skilled labour. Respondent 60 noted that research studies repeat themselves and there are few case studies for solutions: *Information and plans are there for cyclones, storms and droughts but not other risks.* He noted limited coordination between stakeholders along with re-evaluation and risk monitoring studies for adaptation *"Existing funding appears scattered and restricted to governments. Aid is often tied and conditional to donor objectives."*

The budget focused on bringing the $35,000,000 new submarine cable rather than supporting and climateproofing underlying coordinating infrastructure. Existing projects do not focus on preserving stakeholder needs and do not consult past research for cost-effective solutions. Respondent 13 indicates no records were kept historically to enable comparison and preparation. Respondent 21 is concerned that awareness is not filtering to the people and communities. *EMCI has put out several resources and media presentations (on TV and in the newspaper) about preparedness and generally raising awareness. This is done at the start of every cyclone season, and general notices during the season are repeated"* Awareness of legislation is also lacking: *"Our Crown Law office is well behind in producing relevant* *legislation for many important areas impacting on the lives and wellbeing of our country. Technological constraints include there appears no real way to address ocean acidification. SLR adaptation is too costly and not environmentally appropriate."*

Respondent 42 focuses on the need for greater planning, stakeholder cooperation and awareness through information sharing and training: "*People want to come back to something"'* EMCI with 2 full and 2 part-time staff is struggling and beholden to aid-donors, the state financing only salaries and administration. It extends beyond a previous focus of cyclones and disaster risk management to all risk events. To increase awareness, a GeoPortal of vulnerable assets was established. *"One major issue is even though the private sector provides the majority of taxes, they are expected to adapt themselves."* A major issue is the monopoly of shipping company and limited airline cargo options. Both airports and harbours are vulnerable, increased costs are unsustainable. Respondent 30: "*It's a commercial challenge to address cost variations in fish produce due to climate shortages. Social costs exist through the extent of willingness of customers to recognise adaptation costs factored into food costs."*

An Emergency Trust Fund was created to overcome past issues in financing immediate evacuation, impact damage assessments and recovery costs, given delays in accessing donor aid and credit. Government allocated an initial $200,000, now $1,500,000. It requires Parliamentary State of Emergency to access. For droughts, maintenance obligations. Ignoring development without permits formed another barrier to the updated Building Code and restoring coastal ecological attention. Each island has their own disaster risk management plans along with various businesses and government entities, without coordination.

Respondent 31 sees geophysical, environment and land constraints as impediments to adaptation efforts by the information/communication supply chain stage. Maladaptation has a cost for fragile environments. Solutions must not become future problems, and should maintain culture, traditions, knowledge and identity as far as possible. *"Is it worth modernising ourselves and adapting, if it irrevocably changes us?"* Transport challenges include distance; expense; and monopoly providers. It expressed psychological constraints persuading people to become pedestrians, adopt electric vehicles and a less emissions-producing lifestyle, given high vehicle ownership and dependency on imports/inter-island shipping/flights. While some do not cooperate, others may respond to economic, environment, social or other arguments.

Respondent XXXVI envisions disruption to affect telecommunications network and services. Connectivity has been disconnected during multiple risk events for satellites, radio, television, mobile and landlines. They have a challenge knowing who to contact if services are disrupted. However, service provider Blue

Sky Pacific became more knowledgeable in providing redundant networks and cooperating with core government and business stakeholders, if few consumers and smaller businesses. It identifies social and psychological constraints, needing attention: "*There is always a big blow out on Facebook. We prioritise services to key agencies – government agencies, hotels and banks.'* The industry proclaims regular cyclone season checks, standby systems and emergency plans but could not provide specific examples or actual training. It enumerated logistical challenges for emergency supplies to affected islands, given infrequent, expensive shipping and air freight.

7.2.13: Marketing, Marine Tourism and Administration

Respondent 2 (an operator), identifies the commonest adaptation constraint as lack of specific information, unaware of what capital, funding and training are required. Respondent 5 notes stakeholders are conscious yet inactive; not from lack of awareness but lack of incentive. Stakeholders lack access to funding, requiring three different committees over several years. They expressed concern that one event could paralyse the tourism sector (contributing 63.5% of GDP), as occurred historically. The Cook Islands aims for better climate change adaptation through marine ecosystem rehabilitation and the oceans. Tourism operators have to weigh-up long and short-term priorities and investment decisions, with continued pressures to provide returns to shareholders. Less pressure might enable them to respond to mitigation measures, recognising the economic roles of environmental investments. They anticipate risks manifest slowly allowing time to respond. They are unwilling to cooperate despite being mutually interdependent on various supply chain stages Various development and building code policies remain insufficiently enforced. "*If others build on the beach, then why can't I?"*

Respondent XXVIII mirrors concern over labour costs, migration and productivity for marine tourism's future. They mention the need for government support and for community awareness in addition to self-reliance. Respondent 69 notes that adaptation finance is only available to governments and civil society organisations. Few opportunities reach the private sector: *"They are also requested to make significant (NZ $20,000+) investments in things such as septic system upgrades in an effort to increase coastal reef resilience by reducing other pressures. At the same time waterfront properties values are rapidly diminishing because you cannot get cyclone insurance and building permits are a lot more involved requiring EIA's".* They also face constraints from land availability, cost and tourism demands for sea views with pristine beaches: "*We noticed telecommunication constraints, increased commercial fixed costs from airconditioning, high bank interest rates, insurance requirements and not willing to finance when lease times remain short."*

Respondent 33 re-emphasises lack of stakeholder cooperation as constraining mutual adaptation. Most agents, countries and marine tourism businesses compete for the same market, despite joint dependence on pristine functioning ecosystems, fisheries and logistics. The industry indicated planning/zoning problems with the new Building Code review, such as costs of retrofitting infrastructure and ever-changing risk parameters, amongst narrow cash reserves. *"We don't know. All we can do is see what is happening elsewhere concerning climate change and learn from it."* They know individual actions influence adaptation successes, especially ecological rehabilitation and commercial demand.

Respondent 39 considers speed of supplies, action and rapid post-disaster labour mobilisation are crucial to pre-empt further damage, impact costs and vulnerability. Unlike other Pacific destinations a long time has passed since epic catastrophes occurred. If not personally experienced they undervalue it in their daily planning and lives. Most minor tourism operators weigh against insurance costs and adapting, based on costs and uncertainty over the extent of risk. Several indicated communication, training and information challenges when answering if they need to act. They would be eager to cooperate if government was willing to assist, advise and communicate/engage with the private sector. Perceptions focus on self-reliance during a risk event. Some would be willing to repay solution costs in time, if appropriate credit and other constraints were overcome. Most mention constraints of time and money to sustain long-term, marine tourism. They further recognise the need for ecological rehabilitation to secure the future, trying to work with dive operators and others to rehabilitate corals and sea life.

Tourism remains vital, yet is self-guided without clear government vision and support. Understanding the impact on local people's way of life is lacking, especially for those who do not see or experience it. Direct cultural impacts resulting from climate change are not well understood. Physical coastal defences such as seawalls deter visitors whilst others lack necessary climate information for firm risk assessments, which government has. They mention no dialogue between business and government on climate change issues. While they sell themselves as a pristine location, climate change could challenge this. *beaches and corals erode for the foreseeable future, how will it affect the business and economy? Our landscape will change – plants as well. We may become similar to a desert environment … killing close to a trillion dollars conservatively for the tourism sector and ecosystem in the Pacific."*

Maritime administration views inadequate information to reduce transport emissions and secure donor funding as the overwhelming constraint to adaptation. NGOs and international organisations demand and expect high quality data and the capacity to access it. Respondent 21 states even the best response plans, alarms, resources and systems can be meaningless, without sufficient human and physical preparation. In 2017, Samoa had only 7 minutes warning of a tsunami. So many adaptation options and technologies exist, with many designs and local conditions that they struggle to resolve the most suitable. Past experiences indicate problems with physical engineering solutions e.g. seawalls which failed. They echo psychological reticence of other Pacific nations considering *"Our footprint is really small. It's unfair that we are castigated for not doing enough when we are not contributing, adapting the best we can and making an effort." (*Respondent 22*).* They remain concerned about global scepticism, echoed among US, Australian, Canadian and other governments, prioritising short-term, extractive economic growth over mutual survival and prosperity. Respondent 9 notes the state focus on policies, not on practical ways of implementation. The Prime Minister's centralised policy office is understaffed and overworked. It possesses little training in policy analysis. Projects and aid projects concentrate on outputs not outcomes where the focus should be on capturing value for taxpayer dollars.

7.2.14: Financial Sector

Respondent 3 relates the financial sector's main constraint is convincing reluctant offshore banks, brokers and insurance companies to prioritise climate change. The local regulator does not compel them to specific actions, but if they develop a plan – as to what will affect their business and how - they will check its reasonableness for climate change. Banking decide what products and services to offer "*So actual financial institutions actually have a lot of leeway to adapt to disruption, preserving credit and operational risk."* The sector and businesses served remain uncertain regarding specific impacts to generate products and loans, despite having access to globalised risk projections. Respondent 16 notes concern about specific climate change aid funding for adaptation may disappear dramatically, as the Cook Islands undertakes OECD accreditation as Earth's newest developed country.

Respondent 43 presumes fewer risk effects as stakeholders become more aware. Most focus has been on renewable energy rather than other climate change aspects. The financial sector lacks information to accurately determine risk exposure, to offer accurate credit, products and services. Customers need detailed accurate assessments to identify vulnerability. Although PCARFI, EMCI's GeoPortal and aid agencies offer partial data, these are not accessible for most MSC stakeholders. Lack of cooperation, training and information-sharing limits coordination. Stakeholders expressed familiarity about training. "*If we don't have it, we know where to get it from."* Respondent 44 specifically notes the absence of insurance and other products to assist consumers and businesses from specific risk events, lacking assessors, technology and capacity. It might help with existing, solvency, liquidity and operational risks. It mentioned private sector limitations, with firms often monopolies or oligopolies with less incentive to prioritise efficiency, competitiveness, innovation, sustainability and prosperity.

7.2.15: Consumers

Communities demonstrate a variety of climate change constraints restricting complete adaptation including logistics, environmental, resource and others, across risk types. Respondents 24-27 identify existing water, labour and other shortages. Limited entrepreneurial training and awareness for climate resilient products and services exists, despite general consumer and producer awareness. No army exists - people are dependent on each other as a community or vulnerable to external assistance. A spirit of communal philanthropy may assist societal recovery but limits capacity for individual businesses/supply chains to adapt and exploit opportunities. Respondent 33 notes: "*Climate change is evident but comes in unpredictable scenarios making it hard to anticipate which areas to focus on. We depend mostly on government to finance costs."* Respondent 38: *"There is no or not enough funding, medical supplies, water and other goods needed for individual cyclone centres around the islands."* Aid dependency after disasters evaporates independent resolve and initiative. Many believe *"That's the way it's always been done."* Locals lack hands-on practical experience to maintain donated products/projects etc. Government employees have degrees, as do consultants, but lack professional experience. *"Water supply runs out each year but a 6000l water tank should keep you around."* The tanks lacked a spout or downpipe and leaked.

The disaster risk management plan has not been updated in 4 years. High staff turnovers limit institutional memory and capacity. Existing donor priorities ignore local consumer, community and business needs; dissuading efficient adaptation solutions, e.g. the Chinese built local infrastructure using their own labour and equipment but ignored climate conditions and projects failed. Respondent LXVI mentions unwillingness of business and individuals to pay for consequences as a dominant adaptation constraint. One advocated water-reticulation system is opposed by the community as it will discharge and contaminate Muri lagoon and reef. "*Local businesses need to own up."* "*All these aid projects don't matter because aid agencies are not really listening to communities!"* Respondent XXIX signals challenges for business lacking support from aid/state to face the aftermath recovery period, e.g. pineapples and bananas take 10 months to fruit, so they wonder how to survive/minimise disruption when crops, pearls and fisheries are razed. Transport functions only under calm conditions and is expensive for islands to maintain. Respondent 48 echoes these constraints including the viability of preserving outer-island economies given migration and climate change. It indicates issues of ensuring infrastructure and technical compliance with the recently-renewed building code, which applies only to new buildings: *"keep telling them most were built 10-20 years ago. Many Cyclone Martin buildings are meant to withstand* *cyclones but are likely to fail and deteriorate quickly, built of cheap inferior materials. They built cyclone centre meant to lost 20 years. It lasted 12. So replacing it cost $1,000,000."*

Respondent 49 indicates communication and information-sharing problems as stakeholders often prefer to concentrate on individual rather than community or stage impacts and adaptation. Law enforcement and fisheries/ecological protection is hindered by people giving advance warning of patrol vessel's departure to violators. In the outer islands, limited and expensive communication capacity exists for coordination. Many need a radio. Vessels are constrained to 7 days fuel and supplies patrol before needing to return. Respondent LXI reflects some marine tourism and fisherfolk remain so unaware of climate change and so independent of government resources or assistance that they express minimal concerns and constraints, other than environmental/climatic and information. They determined. "*There is only so much you can do to be physically prepared." "Things could always be better but generally can't complain when compared to other nations such as Fiji or Hawaii."*

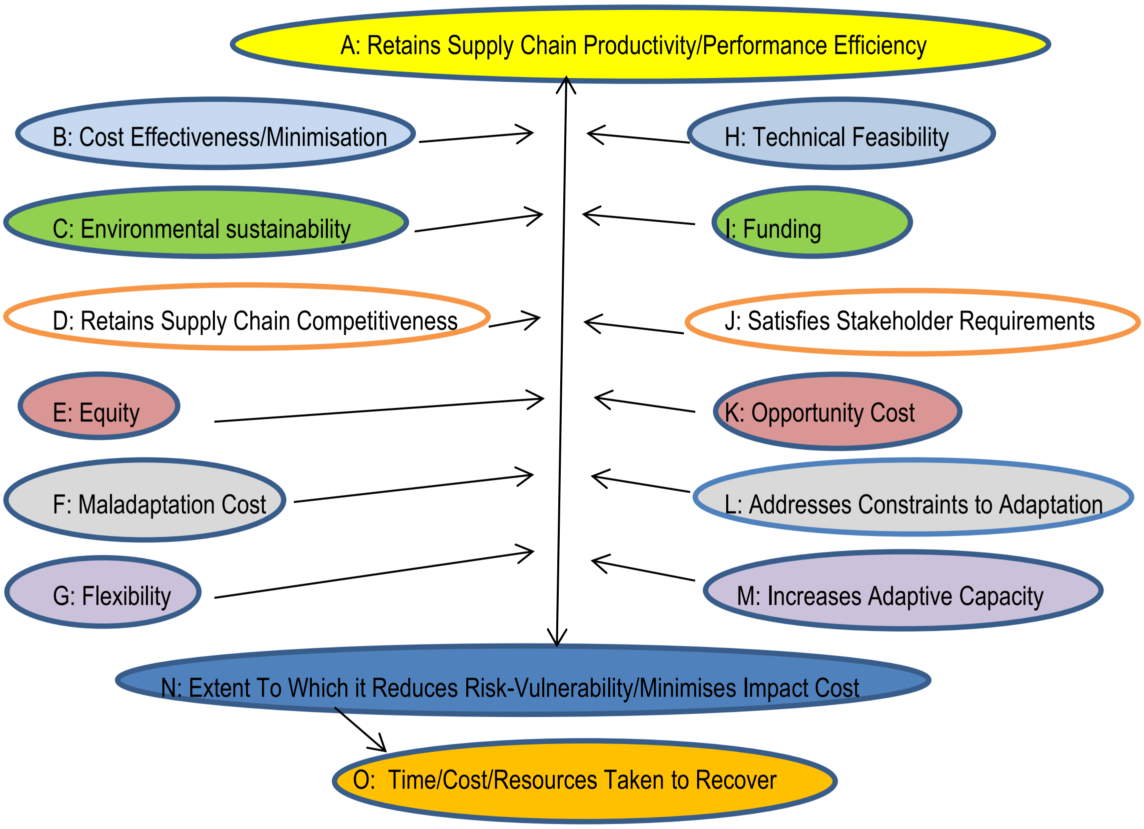
7.3: EVALUATING EXISTING COOK ISLANDS ADAPTATION SOLUTIONS

Stakeholders indicated one adaptation constraint includes existing solutions lack cost estimates and objective evaluation of their comparative effectiveness (Survey Question 7ci). This section addresses how to prioritise adaptation amid sparse or excessive information scattered across myriad sources. It identifies policy types that are effective, providing approximate cost estimates, and ascertains the extent of their effectiveness utilising Figure 7.3. It presents an exploratory approach to evaluate climate change adaptation strategies as outlined in section 3.4. Climateproofing adaptation strategies need to be ecologically and financially sustainable and balance conflicting objectives, preserving stakeholder requirements. They should reduce the risk of damage from climate change events and extent of impact costs across stakeholders, stages and MSC system. They should also address current constraints. Previously, certain hard engineering, adaptation strategies including seawalls were attempted but failed. The Cook Islands prefers to utilise its experience and ensure future survival/infrastructure survival with 100-year time horizons. The following Cook Islands adaptation strategies are evaluated by how much they address climate change risks for Pacific MSCs; using Figure 7.3 criteria A-N as justified in section 3.4.

Climateproofing involves a series of various adaptation strategies to address various issues. To secure marine ecosystems' future from 2012-2016, the 'Ridge-to-Reef' Approach extended maritime sanctuaries, imposed fishing restrictions in days/quotas, increased community-based enforcement, ecotourism and prioritised aquaculture to ensure future maritime food and resource security in its National

Aquaculture Development Plan. This promoted enhancing resilience through income diversification from wild fisheries and improving controlled environment conditions. It received funding to attend a 2012 aquaculture adaptation workshop; technical assistance, documents and training courses.

Figure 7.3: Adaptation Solution/Strategy Evaluation Criteria



Source: Author

It satisfies criteria A, B, D, G, I, M and N. It ignores F, K, L. Criteria C, E, H, J, O remain uncertain. A Cook Islands National Marine Park (costing $32.91 million), with biodiversity species survey has been formed. It covers 1,100,000km^2 of southern EEZ. Its policy framework specifically aims to prevent species extinction. It addresses A-G and J-M. It ignores L, H, I, N and O are uncertain. In 2016 it ratified COP21 Paris and passed a new Marine Resources Bill with stringent enforcement powers, bans and fines from $50,000- $1,000,000 for violations. This believes in rights-based resource management, marine reserves, Muri community management policy, species harvest bans, coastal monitoring ecosystem survey. The 2005 and 2016 Marine Resources Acts call for resource conservation and management. It has established designated fishing rights, aquaculture and fisheries management plans. Its national vision Te Kaveinga Nui aims, '*To enjoy the highest quality of life consistent with the aspirations of our people and in harmony with our culture and environment' with the following core goals: Goal 5: Resilient and sustainable communities, Goal 6: Environment for Living and Goal 7: Good Governance."*

In 1987 after Cyclone Sally the Avarua breakwater was disassembled to armour the foreshore revetment; relocated fuel depots inland and relocated the coastal breakwater, although this failed in 2005. In 2005 the Airport protected its radar and other electronics and secured 3 months fuel supply after 5 cyclones. Construction of Avarua Marina, Avatiu Western Breakwater, sea wall occurred; with offshore breakwaters and tetrapods to protect the runway end. The National Infrastructure and Preventive Infrastructure Investment Plan (Cook Islands Government 2015) requires considering climate change for any maintenance/upgrades to preserve and enhance performance, flexibility and productivity. It answers stages E-H, J, M and N. It ignores A-D and I. L and 0 are uncertain. In 2010 the Cyclone Pat Recovery Plan established $530,416 committed to improving disaster risk reduction in foreign aid. $200,000 was allocated to waste management, $24,000 on a climate risk warning system and $200,000 on general infrastructure resilience. It also allocated $1,356,870 to local economic recovery, conditional on stakeholders considering climate change awareness to enhance future resilience, (which many developed countries have yet to consider). $1,000,000 was allocated to small entrepreneurs, $194,870 to restore livestock and $55,000 for more climate resistant taro production. It follows Figure 7.3 criteria A, D, E and J. It ignores F, G, H, N, O. B, C, I, K and L remain uncertain.

The strategies involved climateproofing public infrastructure such as Mangaia Harbour: This extended concrete hardstand width and precast concrete quay walls to minimise corrosion. It added complete channel widening to minimise wave impacts, relocating the boat ramp south with a beach spending zone north of the existing ramp providing a natural ecosystem resilience zone. This provides benefits of avoided cyclone damage and extended harbour lifespan. This resolves Figure 7.3 criteria A,D,G,H,I,L, and M. It does not answer B,E,K. C,F,J,N,O are indeterminate. It avoided losses to Taio Shipping; losses to fisherman via safe access, and benefits from reduced injury/death. The Port Authority invested $574,203 for wharf strengthening and durability. It allocated $19,660 to magnify safe wharf access during rough seas. Since 2012, risk expectations consider these to reduce maintenance costs. The port constructed a 250mm thick concrete slab, a double reinforcing mesh, perimeter quay platform with concrete wall, wave scour and energy minimisation, concrete barrier wall to reduce cross currents and wave energy dissipation zone. The climateproofed infrastructure project provides improved monitoring and maintenance programmes /training/funding for additional support for Mangaia's local government plus disaster emergency funds.

Other strategies included financial preparation such as the ETRF Fund/Loan Repayment Fund /contingency budget of $819,000**.** This answers stages G, I, L, M**.** It dismisses C, E, F, H, J, and K. A, B and D are unreliable. From 2011 an established disaster response trust fund increased from

NZ$200,000 to 2,100,000 in 2017. PCARFI provides a centralised public infrastructure insurance scheme and asset register for Pacific islands governments since 2013. It addresses criteria A, D, E (for public sector only), F-I, L and M. It ignores C and J. B, K, N and O are unknown. Climateproofing the Islands included improved communication and information awareness: curriculum, training; video and workshops. The Ministry of Marine Resources website provided information on environment, future of resources, central research, business opportunities, careers, ecosystem and fisheries management. It adheres to Figure 7.3 criteria D, G, H, J, K, and M. It ignores E and I. A-C, F, L, N and O remain unclear. Stockpiling/reserves are only informally adopted and indicated from a few evaluated stakeholders for criteria A, B, D, G and M. It ignores E, F, H, I, K, L. C, J, N and O are uncertain. Other tools include Cook Islands Climate Change Biography (Online source centralising past research), disaster risk management plan/profile, online geoportal with data; training and materials. It includes effective coordination through disaster risk management, climate change and stakeholders via a NDRMCCC/local island specific DRMs linking stakeholders, responses, stockpiling and emergency contact points. Te Terai Vaka: (Coordinated Development/Aid Project System) specifically set up with $150,000 maritime. It answers E, G, H, I, L, M. It ignores A-D. F, J, K, N and O remain inexact.

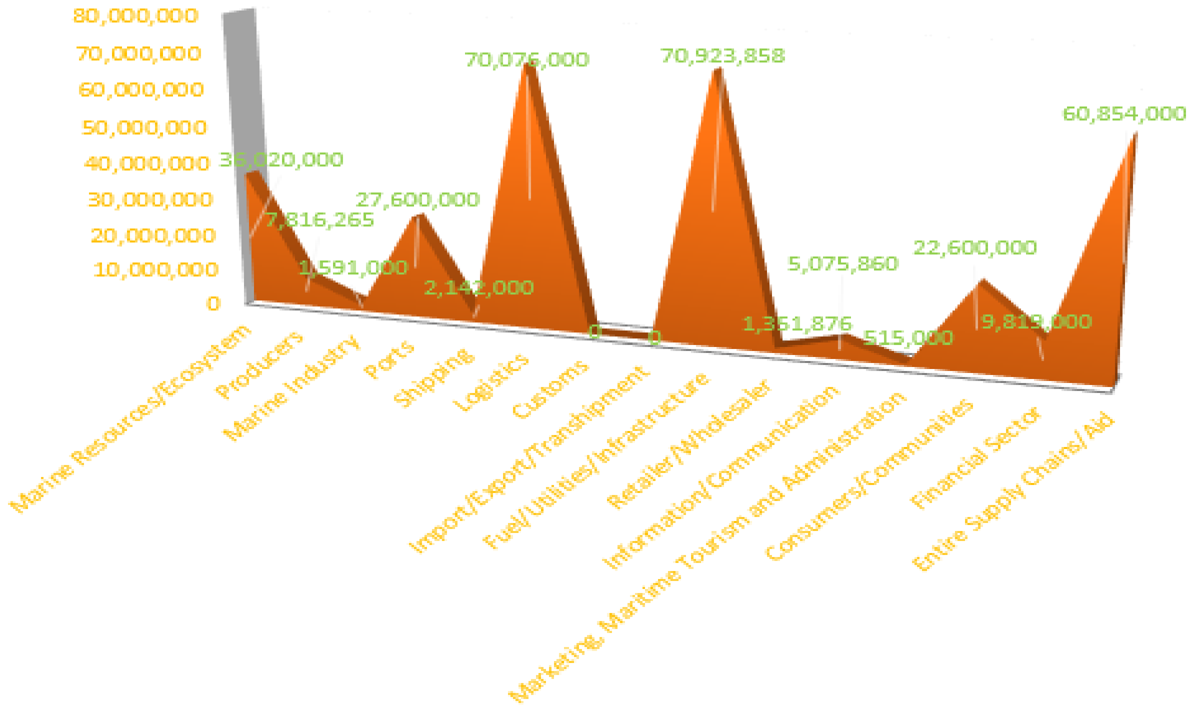
Other efforts involve improving early warning systems to anticipate risks and information gathering. This includes Integrated Coastal Zone Management. SPC (2014) provide a marine habitat map and baseline data, hydrodynamic modelling, geospatial framework, training, research, improved environmental education and institutional capacity building. It included $188,131 on a Cook Islands Coastal Calculator. Coastal risk modelling for Mangaia identified coastal exposure of specific assets given climate change projections. Oneroa village agreed to stop further building in risk exposed area and to prioritise adaptation via evacuation routes, restricting land use and restoring natural vegetation, moving infrastructure inland, elevating structures where possible. It formed a Mangaia Coastal Policy framework. It observes criteria E, H, I, L, M. It ignores A-D. F, G, J, K, N, and O are uncertain from current data. Pacific Climate Futures provided an online tool to connect Cook Islands and other Pacific climate/climate change information) plus climate early warning, monitoring and evaluation systems. PACMAS (Pacific Media Assistance Scheme) recommended increasing media awareness and training for information/communication.

The Cook Islands finally believed in strengthening Institutional Capacity. This extended to the formation of Ministry of Marine Resources in 1984 (policies, research, species information; projects) and creation of Climate Change Division/Emergency Management, Cook Islands. In 2011 this moved to the Prime Minister's Office. It satisfies stages A-C, E, H, L, M, and O. It neglects G and I. F, J, K, N and O remain unknown. It incorporated this into legislation and policy. Regional Pacific plus mainstreaming into various laws including National Adaptation Plan of Action, 2011 National Sustainable Development Plan and aligned to sustainable development/co-benefit opportunities. This adheres to E, J and M. It disregards A-D, G, I and L, F, K, N and O are uncertain The Joint National Disaster Risk Management and Climate Change Adaptation Plan (2011-2015), promotes coordination and collaboration, governance and monitoring across stakeholders to prioritise climate change risk. It follows A, D, H, I, K, M-O. It overlooks C, E, J, and L. B, F, G, M-O lack sufficient information to answer. Each island has prepared a DRM Plan for cyclones/droughts, identified key stakeholders, conducted awareness simulations and shelters.

The Cook Islands remain vulnerable to fragmented stakeholder connections; especially if undermined by other supply chains' inaction across the Pacific region and globally. Unusual events, tourisms' impact, foreshore development and other policies destabilise existing adaptation. The time length since disruptive 2005/2010 events induces complacency. Constraints depend on psychology (stakeholder perception) and awareness of the extent of protection/resilience. Climateproofing is insufficient if the private sector, individual and community do not adapt, possess access to capital, experience congestion or collapse, as assets, financial and natural ecosystems fail. Early warning systems offer limited coverage. Multiple risks exist, yet selective monitoring systems focus on public sector infrastructure. These risks are not considered under developing new business criteria. Tables 7.1/7.2 detail further Cook Islands climate-proofing adaptation cost estimates as approximately $315,638,981. Estimates are provisional from interviews and secondary sources as a minimum indication of how much existing adaptation actually costs.

Figure 7.4 illustrates total existing costs by MSC stage. The most prioritised were logistics and utilities/infrastructure. Customs and Imports/Exports curiously yielded no estimates or examples, accelerating vulnerability. Estimates can be used during future events to determine if solutions are cost-effective and viable over extended periods, given finite resource constraints and numerous priorities. They remain conditional upon resolving constraints and implementing stakeholder-proposed emerging strategies. Costs are influenced by critical asset interdependency, condition, the frequency of maintenance, asset and commodity exposure, training, operation, and vulnerability of outer island supply chains, as factors in Figure 3.4.

Figure 7.4 Total Invested Climateproofing Adaptation Costs for a MSC



Source: Author.

Table 7.1 Cook Islands Existing Climateproofing Adaptation Cost Estimates

Marine Ecosystem/Resources	1997: Burning 20,000 crown of starfish invasion. $120,000 Rutaki Foreshore Revetment; Aviatiu stream embankment $396,000 (2014-2017). Rural foreshore rock revetment $2,600,000
Producers	**Strengthening Resilience of Island Communities to Climate Change (Adaptation Fund)** $47,265 **EU ECHO:** 200,000 euros for food security, seeds, plants, equipment after 2005 cyclones**.** **Agriculture Revitalisation Project** and US–$1,139,200 2017New Zealand **-**$195,000 + $500,000 for fisheries**; World Bank** $5,381,000**,** **EU -**500,000 euros for environmental monitoring/community projects
Value Adding/Marine Industry	**2017 Manihiki** lagoon clean-up: $38,496**,** **Pearl Revitalisation Project** -$130,000 lagoon ecosystem monitoring. China: $1,200,000 for credit/equipment; Cook Islands Government: $68,000 for training/credit. New Zealand $1,165,000
Ports	**Total port adaptation after 2005 cyclones** -$12,300,000, ($600,000 operating and maintenance; $200,000 Atiu; $2,400,000 Manihiki, Nassau $300,000, Mangaia 2,200,000Mauke/Mitiaro Harbour**:** $NZ5,276,490, Penrhyn $900,000, Avatiu Western Breakwater $2,200,000). **In 2017:** Omoka Harbour cost $250,000; Manihiki Harbour $100,000; Orongo-Aitutaki ($750,000) Rakahanga harbour: $865000 Aitutaki-Oranga Port and Marina Climateproofing $15,000,000 (2017-2020). Penrhyn Coastal Protection, Port and Fuel Depot. $4,500,000 (2014-2017.)
Shipping	$12,000 Manihiki barges; $50,000 lagoon dredging. 2017+ 3 aluminium fishing boats Mauke, $100,000 Inter island barge repair; $70,000 Outboard Motor replacement; $260,000 cruise tourism + $500,000 tourism feasibility study (New Zealand Aid). Proposed subsidy $560,000 per ship
Logistics/Transport	**Cook Islands transport sector**: $300,000 infrastructure management for $700,000 for infrastructure service delivery improvement; **Road improvements**: Aitutaki road sealing **-**NZ$800,000; Atiu $200,000; Mauke $900,000; Aroko $400,000; Muri Area upgrade with footpaths $1,500,000. Mangaia Road 3km $600,000; **2**014-2017: $250,000 Mangaia road sealing, **Bridges:** Avarua $5,000,000 (2021-2023), Avatiu Valley $1,500,000 2016-2018, 2016. -$150,000 engineering design/investigation Penrhyn, Manihiki **Logistics**: $500,000 for Outer Island Machinery Shelters; Yato Cargo Shed $8000; Mauke cargo shed $48,000; $180,000 transport truck. Asset Costs $40,000 Aitutaki truck; $300,000 bitumen truck; $915,000 road sealing; $26,000 water pumps. **Airports:** Manihiki $60,000; Pukapuka $20,000; Rarotonga Terminal NZ$ 9,300,000 2024. Instrument Landing System upgrade $3,200,000 (2016-2018). Atiu runway stabilisation $726,160. Pukapuka and Rarotonga Airports Improvement $5,800,000, $200,000 operating and maintenance. Road rehabilitation $8,800,000 construction, $400,000 operation and development
Customs, Import /Export,	No specific adaptation estimates evident
Wholesaler/Retailer	Trader Jack's temporary container **-**$600,000 to repair

Source: Adapted from ADB 2013; ADB 2016; Australia Government 2004, Cartwright and Barclay 2007; Cook Islands 2011; Cook Islands Government 2015; NES 2005.

Table 7.2 Further Cook Islands Existing Climateproofing Adaptation Cost Estimates

Fuel, Utilities, Infrastructure	**Fuel** $50,000 engineering check, $1,450,000 climate adaptation **Triad Pacific Petroleum:** 57-58 days fuel supply. **Pacific Energy:** 4-6 week fuel reserves, 12 week jet fuel storage supply. $250,000 on Aitutaki Fuel Storage Facility (Europe Aid) **Water Supply and Sanitation**: Trunk intake, meters, treatment, Reservoirs $36,300,000. 2014-2018 –Outer Islands Community Water Tank Rehabilitation $1,500,000 2014-2016 Rarotonga upgrade $37,000,000, 2024. $9.4 million water supply upgrade; $4.8 million sewerage. NZ Aid 2006-2009 against drought $2,230,000. -$480,000 topographical water resources survey $168,000 Wake/Pukapuka; Rarotonga Water Upgrades; Mangaia Central Water project $120,000 $2,000,000 water maintenance; $2,098,650 –bridges and drains; Sanitation Upgrades $15,125,208; Northern Water Project $630,000. **Renewable Energy**: Solar PV Mini Grids Aitutaki: -$16,000,000 (2015-2017); Atiu $3,100,000 2015; 2018, Mitiaro -$1,900,000 (2014-2016) Mangaia $3,500,000, $100,000 Rakahanga wind generation. Aitutaki Power $63,000. ADB loan NZ $12,980,000. $480,000 energy efficiency/mitigations. GEF Solar Energy $24,780,000 ($5,830,000 PEC Southern Renewable Energy grant 3,900,000; EU 7,260,000). **Europe Aid – renewable energy, sanitation, water** (2011-2014) $3,300,000 + future $1,400,000 + $4,600,000 to sustainable energy. /$33,000 solar water pumps. $260,000 Mitiaro solar water pumps; $382,000 Pukapuka airport; $3,200 Nassau generator.
Information/ Communication	**ICT Fibre optic cable** $35.0 million 2019-2021 **Disaster Management planning:** 2014-2017: Island Disaster Risk Management Plans created EMCI received $46,000, 2005. 2013 contingency budget –NZ $1,700,000 **Emergency Trust Response Reserve Fund** $500,000 2011; Increased to $1,500,000 2016
Marine Tourism, Marketing, Administration	1997 Cyclone book, T Shirt, Avaiki Pearl Brand campaign (Unknown)
Consumer /Communities	**Outer Islands cyclone shelter** $2,000,000 Rakahanga, Palmerston, Nassau, Penrhyn 2005: EU grant 110,000 euros 2010 **Aitutaki Recovery and Reconstruction Plan** NZ $5,500,000 aid (4,200,000 for homes; Cook Islands government $7,200,000; $300,000 – recovery. Home replacement cost NZ$15,000,000
Financial Sector	PCARFI contributions
Entire MSC/Other	**1987 Adaptation** NZ $29,320,000 -$10,370,000 coastal protection; $18,950,000 other **Cyclone Trina** 2001 received $52,000 aid, **Cyclone Martin** 74,713 Euros2005: $7,870,000 for adapting. EU $280,000; Australia/ NZ Aid $862,576; China $19,200, Red Cross logistics $32000; ADB Cyclone Emergency Assist Programme $4,800,000 loan; UN ECHO Recovery Assist 200,000 euros Mangaia Harbour Climateproofing $1,750,222 + $199,039 roads; $4,800 design. 2010: New Zealand $6,400,000 of a $13,700,000 plan Aitutaki; ECHO/Red Cross - $450,000; 2013: **PCARFI estimate average annual loss** over $4,000,000; EU GCCA-PSIS $800,000; Red Cross $350,226. NZ (5,600,000 2017+ NZ Aid indicate $7,200,000, Australia $2,200,000

Source: Adapted from ADB 2010; Kemma 2012; Pacific Regional Infrastructure Facility 2017; UNDP 2013.

7.4: STAKEHOLDER PROPOSED EMERGING ADAPTATION STRATEGIES

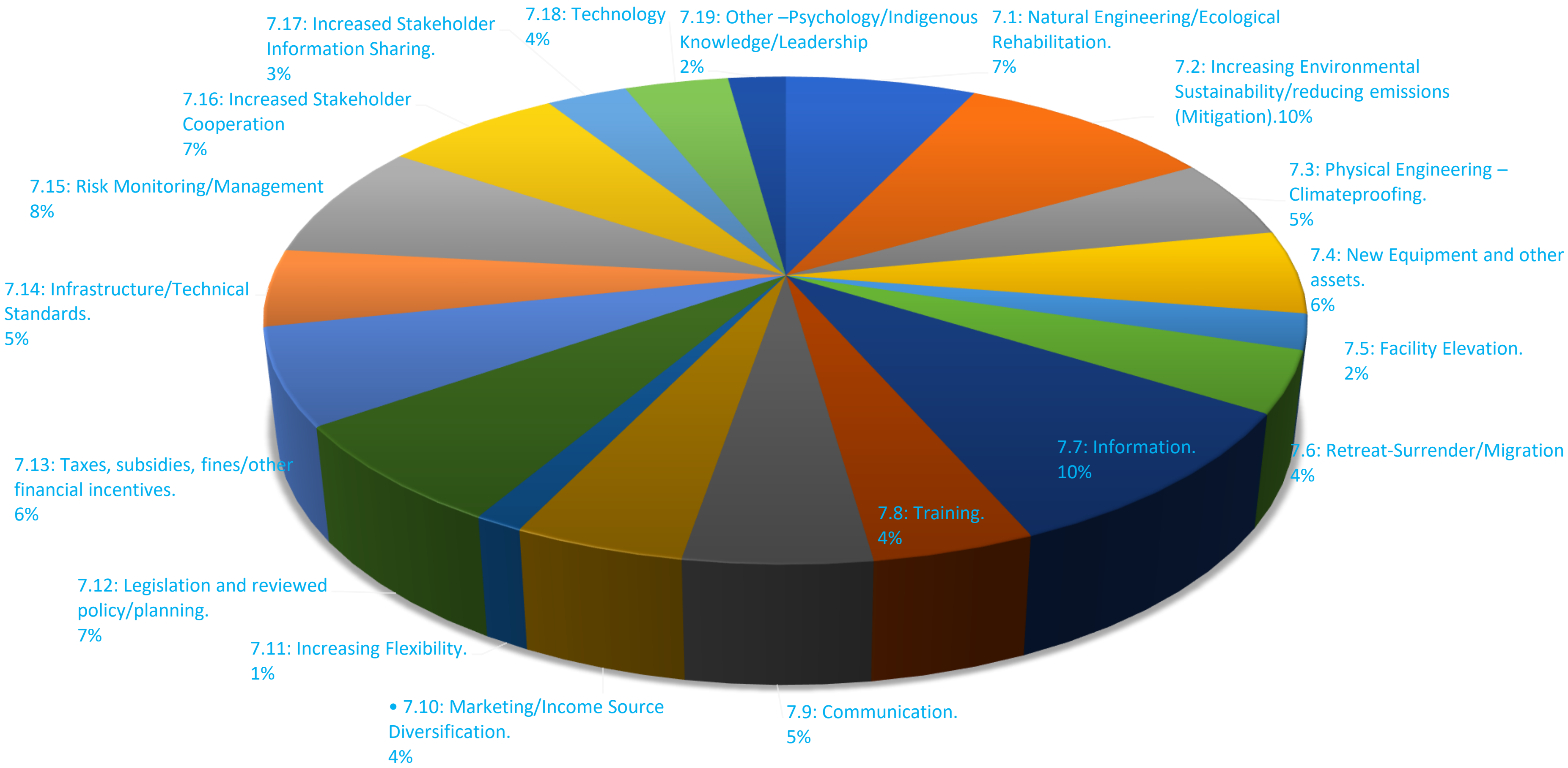
This section presents the survey results on climate change adaptation strategies across Cook Islands, especially questions 6a, 6b and 6c and the open-ended questions (Appendix V) in interviews. Interview duration extended from 17-128 minutes. Stakeholders indicated their preferences for interviews in addition to surveys as presenting greater opportunities, time and flexibility to discuss and develop question responses. Those who had climateproofed were particularly willing to provide more detail. Others were more interested in the chance to participate and influence research. Respondents' statements are not very specific about long term adaptation strategies. 64 participants identified investing in information and research to pre-empt disruption impacts, or mitigation/environmental sustainability as the best, most accessible and financeable approaches (9% of the total solutions mentioned). Enhanced risk monitoring was the third most popular (54). One unexpected result was stakeholders alluding to indigenous knowledge (11) as indicated in Table 7.3. Only 11 indicated no solutions were tried, (the least popular) along with other solution types, becoming more flexible (11) and elevating assets/infrastructure (16). Stakeholder content analysis critically examines individual solution examples from these classified categories so that others can replicate them.

Table 7.3: Indigenous Knowledge, Risk Event Warning Signs

Aether	Land/Ecosystem	Oceans/Ecosystem
Clear Summer	Twisted banana leaf stalks	Abundant stonefish
Mixed seasons –merging together	Disturbed Animal behaviour	Lightning flashes –sea
Birds taking off early December not March/April –golden plover, tropic frigate bird	Abundance of mangoes, breadfruit, guavas, banana	Unexpected fish migration; barracuda, squirrelfish, porcupine fish
Birds flying erratically	Mangoes/Malaysia apples/ breadfruit turn unexpected red	Certain wave patterns
Intense Heat	Unexpected mosquito swarm	Reef/lagoon tinged red
Rising of red sun	Unexpected death of many pigs etc.	Sea Mist/Flashes
Clouds all twisted/thin	Unseasonal fruit –i.e. July mangoes	Fragmented/erratic waves
2 Clouds travelling simultaneously -1 above the other	Chickens moving from roost to ground, noise in doorways	Multiple dead bluebottle jellyfish
Dark cloud rising over sea		Sea really calm
Wind direction sudden change NE to NW		Tide receding far out
		Foam on top of calm sea
		Pebbles in Sea
		Underwater turbulence/tornadoes

Source: Author.

Figure 7.5: MSC Climateproofing Stakeholder Adaptation Strategies



Source: Author

7.4.1: Marine Resources and Ecosystem Climateproofing Solutions

Respondents 19 and 20 prioritise marine ecosystem rehabilitation, research and sustainability, noting its effectiveness with Mare Moana, traditional community managed rauii reserves, replanted vegetation and artificial islands. They are not too sure how economically feasible this is. Respondent 11 commented:

> "*Our organisation is most prepared for precipitation, wave energy changes, storms, cyclones and droughts. We are least prepared for species migration changes.*" "*We raise awareness and provide advice about nature-based solutions to climate change impacts. We have included it as one of our five focal areas alongside biodiversity, waste management, ecologically sustainable development and youth.*"

Respondents favour education and awareness via collaborative research reports, social networks, dedicated media articles and websites. With greater resources they would favour more long-term coral reef monitoring, species surveys, information testing stations and greater technology (beyond water quality). They view education as key to understanding climate change impacts and adaptation for communities (Table 7.4). They believe in individuals' impacts regarding mitigation and being more environmentally viable. Research could target the implications of losing keystone species on the remaining ecosystem. Ecotourism can be marketed as more sustainable options.

Table 7.4: Ecosystem Adaptation Strategies

MSC Stage	Respondent	Adaptation Strategies (% Of Respondents Pursuing/Favouring Strategy).
Survey **Interview**	**XIX, XX** **11, 27**	Mitigation/Sustainability (100), Natural/Physical engineering (100), Information (100), Stakeholder Cooperation/Information Sharing (100), Communication (100), Ecosystem (75), Risk monitoring (75), Infrastructure (75,) Policy (75). Financial incentives (50), New assets/equipment (25), Climateproofing (25), Training (25), Flexibility (25).

Source: Author

7.4.2: Producers

The survey and interviews indicate fisheries producers have not prioritised adaptation. Respondent LI reflects a fisherman who has not adapted. He is independent of the state, tourism sector or others. He operates a small vessel and is not really interested in support for adaptation solutions, yet highly risk concerned. *"There is only so much you can do to be risk prepared. I get enough climate information from media/service. The boat ventures out when calm."* Respondent 35: *"We retreated and relocated, securing premises and* *transporting stock, to save storage to survive as the best doable and economic strategy." "It's all about ensuring sustainable fisheries."* (Respondent 40).

Respondent XLVII interlinks marine ecosystem protection with conserving sustainable fisheries even under climate change. She mentions the creation of the first Pacific Islands Total Quota System, designed to input, record, monitor, catch and release so every species' and individual's fate can be monitored across the EEZ. "*There is a focus trying to see what has been caught and not caught from different perspectives. We collect evidence and interview captains, settling for a fine. If they refuse to comply, we threaten to blacklist the vessel."* Fisheries cooperation agreements have been ratified with other Pacific nations. To counter scarcity of observers and law enforcement, greater technology has been deployed, including satellites and port security cameras to monitor wharf usage fishing/day. Incentives and electronic logbook monitoring, licensing and random patrol inspections focus on compliance. Observers have tablets to instantaneously upload data rather than physically inputting it previously. A program exists to support artisanal fisheries with subsidised fuel, access to equipment and storage/refrigeration facilities, conditional upon registering them, vessels and catches electronically in a Cloud. "*Getting reliable accurate 100% data is a work in progress".*

She envisions future solutions could activate more marketing, technology, education and social media (Table 7.5) to get youth to participate in fisheries conservation. This ensures resources avoid extinction for future generations as in her view everything is linked to climate change – money, livelihoods and food. She believes that regional Pacific collaboration in SIDS will be more effective

> *"We will have more weight and be strong if islands and leaders come and work together for a regional approach to quota management system. Our fisheries would be much more valuable. It would increase our revenue by 300%. It just takes smart leaders and leaders moving ahead. Anything is possible, if you manage your resources. We will have greater power and control over resources to cope and adapt."*

Table 7.5: Producers/Fisheries Adaptation Strategies

MSC Stage	Respondent	Adaptation Strategies (% Of Stakeholders Pursuing/Favouring Strategy).
Interviews **Surveys**	**X, VII, LI** **17, 18, 19, 20, 23, 38**	Risk monitoring (44), Mitigation/Sustainability (33), Natural/Physical engineering (33) New assets/equipment (33), Stakeholder Cooperation/Information Sharing (33), Information (22), Communication (11), Ecosystem (11), Infrastructure (75,) Policy/Planning (33). Climateproofing (25), Training (25), Financial incentives (11), Flexibility (11), Migration/Relocation (11), Income Source Diversification (11), Infrastructure-Technical standards (11); Retreat/Surrender (11), Technology (11).

Source: Author

7.4.3: Marine Industry

The marine industry has invested in pearl aquaculture to resolve existing wild fisheries pressures. Chapter 5 analysed advantages of an approach aiming to ensure sustainability through traditional rauii reserves, a lagoon management plan and farming code. The Pearl Authority currently lacks industry sector confidence to aid in ecological rehabilitation, marketing, training and credit, as noted above. Current wholesale auctions contribute to financial insecurity. Stakeholders have alleged insider manipulation and low profit margins. They favour wholesalers not distinguishing in hue, quality or otherwise. Respondent 7 noted the need to preserve existing marketing messages of sustainable pearls aiding remote communities on South Pacific tropical islands. Greater research over lagoon conditions is also advised. "*As conditions change people recognise, they need to adapt but they need to sustain their livelihoods and know what to do.*" Yet, stakeholder expectations of solutions remain concerned and uncertain. *"How will they know what to buy to adapt? Where? How will it be maintained? How will it be financed? How will I know the traders and supply chain and they are cooperating? If broken can it be easily fixed?"* The government could negotiate on bulk orders for equipment, offering economies of scale and more effective seller and resell/distribute for more reasonable market prices.

The sector sells pearls mostly to tourists but would like to expand overseas. Respondent 55, a pearl farmer, suggests "*One can create the infrastructure and welfare; but without creating the economic situation, this offers few substantial prospects and commitments to the future.*" He proposes handicrafts, supporting local culture and provide a market/assistance as with the Pearl Authority. MMR need proper coral inspections to understand climate change. He argues the pearl lagoon needs 5 years recovery to remain productive. The Pearl Authority allows local shopkeepers to select the best specimens, so farmers do not necessarily get the best prices. Greater marketing support would help with Internet auctions and overseas destinations. Pearl farmers cite no evidence of future vision, coordination, research, marketing promotion, technology or leadership, 'nothing but excuses.' They are not seen to be cooperating with tourism and others to develop products or the industry. CIPA get $500,000, they are not perceived as needing more. He proposes more students and researchers to benefit and improve local conditions. "*Local people need to be aware that business is not immediate it takes to survive 18 months minimum without a break as a business."*

Table 7.6 classifies proposed solutions. Respondent XIV's pearl farm has adapted to higher SST's by physically moving them further down, only adding sensors 5/6 years ago, resolving poorer lagoon visibility. Other farming methods have changed, reducing oyster stress as they have weakened. New edge drilling minimises diseased oysters being retained. Aquaculture pays attention to mobile and email climate alerts from MMR. Many perceive it as an industry lacking a future. "*To start and survive, you need deep pockets and exceptional marketing skills. Need more of a niche market to get the biggest margin" (XXXV).* Stakeholders proposed open bidding Internet or local auctions would offer greater financial security. They are open and time-bound allowing multiple bids. To reduce labour constraints, a population policy is proposed. It should consider projected demand, supply and skills. "*We have to factor in foreign labour, cannot run pearl farms without them. What population do we want and what kind of rights/aid are they entitled to? You don't plan, you don't think ahead; you will end up in disaster."*

Table 7.6: Marine Industry Adaptation Strategies

MSC Stage	Respondent	Adaptation Strategies (% Of Stakeholders Pursuing/Favouring Strategy)
Interviews **Surveys**	**XIV, XXX, LV** **24, 29**	Mitigation/Sustainability (80), Natural/Physical engineering (80), New assets/equipment (80), Stakeholder Cooperation/Information Sharing (80), Information (80), Training (60), Ecosystem (60), Financial incentives (60), Risk monitoring (60), Communication (40), Infrastructure (20) Policy/Planning (20); Flexibility (60), Migration/Relocation (20), Income Source Diversification (20), Infrastructure-Technical standards (20); Technology (20).

Source: Author

7.4.4: Port

Existing emphasis has targeted climateproofing port infrastructure. However, Respondent 9 expressed concern over failures during the first storm, no training for safety and health officers. When asked about the experience in dealing with climate change, an engineer replied "*Zero."* Respondent 15:

“*We’re concerned about a lack of financial resources to restore infrastructure from natural disaster destruction. Applying for adaptation funding afterwards would delay any restoration. We have interacted over climate change through Maritime Forums especially Pacific Ports”*

Respondent XXXII notes existing adaptation during events is an informal port stakeholder agreement to move mobile, vulnerable assets, cargo and vessels to less exposed conditions. 100 containers on the wharf on average are exposed. “*You can only do as much as you can but that’s better than doing nothing at all.”*

Table 7.7 identifies individuals’ responses. The aim is to restore port operations in 24-48 hours, with records backed up, regular staff and port user drills, extensive coordination, cooperation and information access. “*Every weekday finance manager backs up. One is manual and other is automatic saved to Blue Sky. Every Friday, they back up everything. We have exercises to familiarise themselves especially managers because the rest of the staff only take orders from them* Climateproofed infrastructure, prepared for only 0.5m SLR, has yet to be tested since 2010 for a cyclone although it weathered the 10m sea surge in February 2018. When pressed for specific solutions, Respondent 36 recorded an ambiguous answer. *“Everything is equally important. The more we can do to reduce emissions or adapt the better. We would benefit on information about the effectiveness of specific port solutions.* “Infrastructure’s success depends on whether users have money and resources to improve it. *“We don’t know how fast climate change will happen; it could happen tomorrow. That’s why it’s important to act now to be effective!”*

Table 7.7: Port Adaptation Strategies

MSC Stage	Respondent	Adaptation Strategies (% Of Stakeholders Pursuing/Favouring Strategy)
Interviews	**XV, XXXII**	Physical engineering (100), Information (100%), Risk monitoring (100)
Surveys	**15**	Financial/Funding (67), Infrastructure Technical Standards (33), Planning (33), Information (33), Communication (33), Retreat/Surrender (33), Relocation/Migration (33), New equipment/assets (33), Training (33).

Source: Author

7.4.5: Shipping

The Maritime Transport Policy, (Cook Islands Government 2014), “*establishes policies to guide the planning, actions and strategies necessary to local port infrastructure and all shipping services operating within the Cook Islands. These must be compliant, safe and secure and pose no threat to the marine environment.”*

This could be revised to factor in and implement climate resilience. Respondent IX advocated the authority's solution to logistics constraints, to aid more viable outer island economies and users "*Our party would have open discussion with local operators on ways of assisting through subsidies or fuel rebates as incentives for improving shipping services."* Other adaptation options proposed include special charter options, rotational schedule utilising fishing boats, local shipping operators and the patrol boat on an as-required basis. Charter vessel usage is considered expensive and not good value for money. They propose co-financing needs long-term viability and cost-benefit analysis on actual cost, what services can be provided and sources of funding. A subsidy needs to consider the beneficiaries, type needed (income enhancement, lower effective prices, increased consumption), value and most capable delivery mechanism to attain to objectives and benefits. The cost was estimated in 2012 as $360,000 paid quarterly or voyage plus $200,000 administrative costs.

Respondent XIII indicates personal, physical and psychological training and gathering information to adapt to climate change as a shipping operator, promoting self-reliance. *"Some just told not to repair engines – say get a new one. We say repair it."* If a disaster happens vessels must go to safer harbours on the leeward side of Rarotonga, but none exist. He mentioned past seawall and breakwater failures, wasting money. He also proposed investigating waste sources, i.e. chemicals discharged and implications for fisheries, food and water security. *"In the balance, if we create something, we may bring problems somewhere else"*. He mentions solar panels saved 2,000,000 litres of fuel going north, (worth $1,500,000 p.a. from imports). Yet renewable solar panel energy was a past French aid project failure. "*One cyclone took the propeller away. Posts/wires were found all in pieces after flying miles away."* He has not encountered solar panels capable of withstanding 170-200kph winds unless reinforced perhaps in concrete. However, vessels, technology and climate information access has been invested in to increase resilience. "*You are the scientist and in charge of the environment for solutions. As the younger generations it's you who will have to pay and live with our mistakes. Really the main issue is to preserve normal living as much as possible."*

Respondent 14 feels they are unlikely to qualify for adaptation funding. Although systems are fairly robust, a direct hit cyclone would cause outages for a few days. Each asset took 3-4 days to recover. *"Communication is a major cost for us but repair costs after natural disasters not borne by us. We have business interruption insurance. Some opportunity costs exist if we had to relocate to Auckland in the event of no electricity or Internet for more than a week."* However, their overseas office would prevent major sales revenue/disruption consider loss of life/health is unlikely as they heed warnings and take precautions. "*We moved to a cloud-*

based IT system. We need the register to be available to authorised users anywhere in the world. We've invested in physical engineering/climateproofing, new equipment, technology and other assets".

Business believes it is most prepared for SLR, storms, cyclones and tsunamis. They have noticed there is plenty of information:*"We have not considered information sharing and cooperation with others as we don't think we need to."* Table 7.8 summarises participant responses. Respondent XLI as a shipowner comment:

> "*We are in a tiny vulnerable place; everything is blamed on climate change but we do have a business continuity plan. This plan is a combination of insurance and risk management – power, water, Internet disruption. If there was an event we fly out or relocate away from sea surge to a house. We prepare with shutters and move stuff up the hill."*

Many remain concerned about the lack of a backup port. *"We have Aorangi harbour channel – supposed to be climateproofing back up; so we can try to at least survive. We will survive on yachts even if islands are no longer as prosperous and supportive."* They do not seek adaptation funding or other assistance "*The Cook Islands are quite creditable at hooking into local fashions and quite good at getting money, much better prepared than large nations. They take it seriously because it affects them."*

Respondent 38 believes in humanity's power to devise technological answers to climate change; common among shipping/logistics as for tourism and marine resources. Weather forecasting is determined as sufficiently adequate to factor in climate change and for vessel robustness, with enough warning. Given the impracticalities for intermodal transport and challenges in converting towards greater autarchy, even more pressure will be required on shipping. International trade does not support localism, even if that produces fewer emissions. New ports will need to be climateproofed. People must know how to specifically respond; whether to shifts in marine ecosystems, cargo, climate, environment, technology or impact costs. He proposes being more environmentally sustainable, substituting products and operations, to reduce externalities wherever possible.

Table 7.8: Shipping Adaptation Strategies

MSC Stage	Respondents	Adaptation Strategies (% Of Stakeholders Pursuing/Favouring Strategy) s
Interviews	**XIII, XXXVIII, XL, XLI; LVII:**	Fiscal incentives (83), New assets/equipment (83), Natural/Physical engineering (83), Risk monitoring (83); Mitigation (67), Technology (67), training (67);
Surveys	**14**	Market/Income Source Diversification (67), Stakeholder Cooperation (67), Policy/Planning (50%), Information (50); Elevation (50); Indigenous knowledge (33); Infrastructure- Technical standards (33), Retreat/Surrender (11), Ecosystem (11), maintenance (11), Flexibility (11), Relocation (11)

Source: Author.

7.4.6: Logistics and Customs

Table 7.9 summarises logistics solutions. Shipping company Respondent LXVII warns of ignoring essential port users. The harbour mouth is just 3-4 metres and needs expanding to service container shipping or cruise ships. If windy, swells risk capsizing and navigation. Risk is determined by the vessel's captain. "*There is always a plan in place. What if climate change happens? Do we go back to our principal and mention it or act?"* Larger vessels still have to wait during risk events and some need to evacuate. The perception is that, aside from protecting local fishermen, it is money mostly wasted. Design stages are not technically efficient for wave breaks. A second more protected port is recommended by operators, which would be extremely costly and incompatible with coastal geomorphology /scarce existing land constraints. They envision rapid increases in import volumes to appease tourism but decreasing exports. Vessels have limited space and 14 days turnaround. Reserves are constrained, users unable to overstock but maximising potential disruption during a risk event. During events, many agent offices are mobile containers and relocatable. They help ports to remove cargo and equipment/containers/vessels. Insurance is standard. Every 1-2 years the port conducts live emergency scenario exercises with users, so regulars are considered well aware of all risks.

Table 7.9: Customs and Logistics Adaptation Strategies

MSC Stage	Respondent	Adaptation Strategies (% Of Stakeholders Pursuing/Favouring Strategy)
Customs Interview Survey	**X 30**	Fiscal incentives (50), Information (50), Mitigation/Sustainability (50), Training (50), New assets/equipment (50), Flexibility 33),
Logistics Interview Survey	**XI, XII 26, 28**	Technology (11), Stakeholder Cooperation (11), Elevation (11); Flexibility (11); Risk monitoring (11); Natural/Physical engineering (11); Ecosystem (11), Infrastructure (11), Policy/Planning (11), Market/Income Source Diversification (11),

Source: Author

7.4.7: Wholesaler/Retailer

Table 7.10 details respondent strategies. The business promotion agency is targeting commercial adaptation. *"We are cooperating with Climate Change Office on projects to assist in ensuring businesses are sustainable" (*Respondent 17). *"Some change and reform practises for a few years. It has an impact but then when others do not, they revert."* Respondent 18 considers: "*training small businesses on insurance, preparing for natural disasters and savings to recover".* Businesses have seldom acted but need to prioritise climate change commercially for resilience via training, credit and mutual interaction. The agency has investigated providing specific eligibility criteria, resources and improving policies. This aims to rectify past state neglect of the private sector to ensure businesses also continue, ensuring they are equipped and trained to be resilient. It argues the private sector can have a greater multiplier impact for future recovery, food security, trade and survival than aid dependency or targeting communities. It advocates including them in disaster recovery strategies. "*We know disaster management have plans to restore electricity, water, canned food etc, but not for private sector."*

They suggested qualification criteria could include being a registered taxpayer, trading for two years, the business is a full-time source of funding/only income and conditional on drafting a sound recovery plan/attending training to moderate disruption costs. ***"****Being resilient means being able to address it better and having the resources to do so."* It wishes to advise investors with periodic communication as risk conditions change. Respondent 1 noted business demand stimulated adaptation, proposing disaster aid for trade to revive outer island economies, to secure sustainable finances. Recovery presents a prospective opportunity to become more resilient.

Table 7.10: Wholesaler/Retailer/Import Adaptation Strategies

MSC Stage	Respondent	Adaptation Strategies (% Of Stakeholders Pursuing/Favouring Strategy
Import/Export Interviews **Survey**	**I, XVII, XVIII, XXVIII, XXIX; XXV** **34**	Fiscal incentives (46), training (46); New assets/equipment (31), Natural/Physical engineering (31), Risk monitoring (23); Mitigation/Sustainability (23), Technology (23), Market/Income Source Diversification (31), Stakeholder Cooperation (15),
Retail/Wholesaler	**LVI, LIX** **8, 9, 10, 39**	Policy/Planning ((23) Information (23); Elevation (23); Infrastructure-Technical standards (23), Legal (15), Ecosystem (15), Flexibility (8), Relocation (8), Communication; Relocation/Migration (8) Indigenous knowledge (8);

Source: Author

7.4.8: Utilities and Infrastructure

Respondent 28 establishes "*Whilst climate change remains as one of the most concerning Cook Islands topics, the government approach needs to be prioritised. We are one of the first Pacific Islands to start putting aside funds for climate impacts. We are driving infrastructure across all islands".* For it to succeed various entities believe it needs to lift its profile and reputation in addressing all of the above climate issues. Respondent 31 said several stakeholders have been involved in climate change for some years, having contributed to climate change studies, designs and implementations. They are also involved in disaster risk management, both at a national and community level.

Respondent LIII has implemented various solutions for fuel utilities, valuing natural sandbanks to deflect waves and currents and vegetation offering coastal protection. They fill tanks with water to weigh them down and secure locking mechanisms. They move mobile LPG tanks to inland/less exposed location. Disaster plans aim to secure products but only focus on training for fire disaster scenarios. They are insured against business disruption but lack signs of information and communication cooperation over effective risk management. Fuel needs to be shipped from Fiji/New Zealand every two months but they possess a two-month fuel supply. The company has proposed needing $4,000,000 for a new pipeline and tankers offshore to avoid the exposed harbour. Its professed advantages, aside from climate resilience include being more secure, safer, environmentally friendly, reliable and transfers larger volumes. However, it has been rejected. He proposes a tax rebate for capital infrastructure; ensuring a stable fuel security supply, (although analysis projects lower volumes as necessary, once 100% renewable energy is attained).

Table 7.11: Utilities and Infrastructure Adaptation Strategies

MSC Stage	Respondent	Adaptation Strategies (% Of Stakeholders Pursuing/Favouring Strategy)
Interviews Survey	XXXIV, XXXV, XLV, XLVI, LIII: 33	Infrastructure Technical Standards (100), Planning (100), Physical engineering (83), Mitigation/Sustainability (67), Information (67), New equipment/assets (67), Training (67), Communication (50), Retreat/Surrender (50), Relocation/Migration (50), Other/Indigenous knowledge (33), Legal (33), Market/Income Source Diversification (17); Financial incentives (17), Stakeholder Cooperation (17),

Source: Author

Respondents XXXIV and XXXV climateproof infrastructure through orthodox coastal protection methods. They recently upgraded 1980's rock revetments for sea surge. One businessman's incentive included tetrapods deflecting currents by the airport runway edge and coastal road. Government wishes to work with businesses to become more climate resilient via the Building Code. Proposals need peer-to-peer evaluation on projects for adaptation, not just signed off by engineers. The Code specifies 91m/s wind speed and Cyclone Category 5 standards. Elevated structures will avoid ground floor residents by using space as storage/garage/temporary room. Evacuation routes are planned. Water storage tanks/a reticulated system and renewable energy installation aims at self-sufficiency for utilities as future climate change priorities. Infrastructure would greatly benefit further for ongoing maintenance and asset management under transformed climate conditions.

Respondent 45 indicates 100% renewable energy by 2020 as electricity solutions to mitigation and adaptation, lowering needs for fuel and other imports. However, individuals expressed concern as to credit access, storage and distribution capacity. Excess bureaucracy to access donor aid meant the Renewable Energy programme took 2 years to get training, 2 to get operational for $200,000. No specific recovery plan or training has been published or provided to achieve the goal of restoring emergency operations within 48 hours. The server and offices are prepared It lacks formal sector participation and the electricity company was perceptibly reticent at committing to specific answers. The initial concept was the networking, smart metering and Independent Producer's Programme with solar generation fed back into grid. Incentives included a plan to ensure affordable, reliable energy to consumers, as a revenue generator, power saving and emissions reducing/sustainable. They detailed concerns with the feed-in tariff, storage and distribution capacity, delays, bureaucracy, poor timing, along with stakeholder reactions. It focusses mostly on wind and solar but aesthetic aspects dissuades wind. Respondent 46 said: "*I was told to meet. Information helps us* *plan for the future and we take on any reasonable solutions. Climate change is an issue our leaders are talking about and we are committed to it."* During an event they have inventory reserves of basic parts and 3 months fuel supply. Personnel are briefed, on standby for deployment, getting overtime.

7.4.9: Information and Communication

Table 7.12 re-emphasises the most implemented stage solutions. Respondent XXX proposes translating and simplifying climate change information for local communities. She pioneered science fairs to help children understand and participate in conserving the marine environment. Numerous community workshops and consultations contributed to the high proportion of motivated, risk-aware stakeholders contributing to this research. Past experience forewarned against leaving the community to face an event aftermath inadequately prepared. It signalled the importance of species monitoring and logging to help MMR and understand marine resources status. Personal safety bags were introduced to all vessels and settlements: "*All boats should each have a mobile phones and strobe lights for nocturnal fishing. A lot of fishermen did not have access to ice or chilling facilities just used coconut fronds. We applied for new equipment and funding for the chance to address isolation, safety and precautionary measures, creating value adding products such as tuna jerky." "As a pearl farmer I check local conditions and weather frequently."*

To improve communication and overcome psychological barriers she hinted for someone fluent in both languages, not just a scientist: *"Diverse background; culturally aware of changes; who has historical knowledge as well. If you were just a researcher (outsider) but do not understand the stories, then the barrier goes up. But if you can make comparisons in the past; in the future; regionally what is happening to other islands …. you stand a chance."* In past events e.g. the 2005 and 2010 cyclones, there was no idea of the specific information needed to ascertain specific risks, impacts and adaptation priorities. Respondent 42 proclaims the Geo-Portal, a centralised database of climate change risk, will aid the information and communication stage to alert and adapt others. The idea is to identify buildings' vulnerability to Category 4/5 cyclones, enacting a damage assessment. However, as with the Pacific Catastrophe and Risk Finance Initiative (PCARFI) these databases were inaccessible. Government and NGOs have initiated training workshops and research, and composed documentaries to record cyclone early warning signs' traditional knowledge. PCARFI is a mutual public insurance, finance cooperation scheme established by 5 nations including the Cook Islands. It paid out for a Tonga flood. If needed, a $10,000,000 potential loan agreement exists with the World Bank as credit for public sector recovery and adaptation. Risk information and education is imperative for properly targeted and capable funding.

Table 7.12: Information and Communication Adaptation Strategies

MSC Stage	Respondent	Adaptation Strategies (% Of Stakeholders Pursuing/Favouring Strategy)
Interviews **Survey**	**VII, IX, XXXI, XXXVI, XLII LII:** **1, 12, 16, 21**	Stakeholder Cooperation/Information Sharing (70), Mitigation/Sustainability (60), Information (60), Risk monitoring (50), Policy (50), Communication (40), Marketing/Income Source Diversification (30), Ecosystem (20), Financial incentives, Infrastructure, Flexibility (20), Natural engineering, physical engineering (20), Technology (20), Training (20), Retreat (10), New equipment/assets (10), Elevation (10), Other –Indigenous Knowledge (10), Psychology (10), Legal (10) Migration (10).

Source: Author

Leadership is viewed as fundamental to awareness and adaptation. "*If you were to call a meeting –best to involve traditional authorities and significant individuals recognised locally to ensure attendance to do things" (*XXXII*).* People can accurately assist and know the extent of the disaster/solutions. To be better prepared, networking on climate change goes in parallel to risk reduction. Climateproofing infrastructure considers future climate change and not just buildings, looking at long term adaptation and risk reduction "*You cannot just erect something without future climate change considered".* For example, substations and resorts are still located on floodplains. Marine ecosystems are given time to recover from fishing as preferred adaptation.

Existing research/aid projects may face failure, having been developed without local community awareness and consultation. The information/communications sector appears generally interested in research. It understands the worth, given past experiences and disasters. Respondent 60 feels investment in research, forecasting capacity, mainstreaming into policy and establishing reserves are important: *"Psychological expectations and behaviour should be prioritised as previous research has focussed on physical infrastructure."* Respondent 25: "*The Cook Islands have a Disaster Management Division; whose main function was to deliver awareness programs or workshops pertained to environmental impacts and response solutions in both internal and external aspects."* Respondent 31 identified substantial aid sources have prioritised community awareness, mitigation and adaptation (if with some noticeable voids). He serves as an exponent of indigenous knowledge (Table 7.3).

Ideas implemented must not just appease aid agencies or investors, but aid progression to the future stakeholders want to create. Interviewees cite electric vehicles via fines, law and tax incentives, present problems of disposing 9,000-10,000 existing vehicles. Electric vehicles just received the first charging station, but they need the look and attitude/marketing to appeal to consumers. Transport fuel usage is high and inefficient, needing to reduce emissions. He favours psychology solutions via training to convince people to change. *"Human nature always looks for the best deal. We need the same mind-set over the environment."* Eco, fiscal and psychological incentives can alter consumption and production processes. Stakeholders have been counselled of learning from other countries facing similar challenges. Going forward; do not develop areas for the sake of growth given climate projections. This helps to set priorities, directions and check all aspects thoroughly for feasibility, appropriateness and sustainability before converting to green technology.

Respondent XXXVI establishes telecommunication adaptation solutions as the need to preserve communications and connectivity with others. It advises building redundancy capacity into network service capacity. He refers to the bush fire which occurred just before this study: *"Two sub stations burnt and our main connectivity to outer world by satellite. We had resiliency – were able to maintain Internet connectivity via extra capacity and partnering with Samoa using their capacity eventually. We focus building relationships with service providers, suppliers and PICTA for mutual assistance during disasters"* They keep basic minimum spare parts. The aim for climate change is to try and maintain essential services, to keep more spare parts and reserves – even on most isolated supply chain locations. The primary concern is to protect generators: *"As private businesses, don't really need anything from government to adapt to climate change nor see anything much for them, just continued support and willingness to invest in infrastructure and services when necessary."*

Respondent LXII emphasised how critical regular climate information updates are with meteorological stations and access to high resolution satellite data, combined with stakeholder cooperation. He mentions awareness, education and training linked to experience can motivate action. During past events, cyclone shelters were identified and resorts were meant to cater, equip and prepare visitors but many tourists preferred to chance their vulnerable beach resorts:

> "*It's evident psychologically they couldn't comprehend how a warning system and disaster response plan were meant to function for 2005. Most resorts clearly didn't provide or explain support, plans and processes -so confusion, even though would be safer to secure themselves at the resorts to ride out these warnings."*

Others decided to fly out as soon as possible. Airports were closed yet tourists insisted on waiting there. *"There is no way it can take off. So why not wait and have faith in the government's ability to respond?"*

As respondent feedback evidenced, the information/communication sector is expected to both contribute more to policy research and towards mitigating risks of climate change and vulnerability. The roles of quality monitoring processes are maintained to consider emergent risks. The 1996 Act mandates Meteorological Services to provide information and early warning systems. Monitoring stations are proposed for all islands: *"The challenge remains that we are equal to how we can secure our livelihoods and adapt".* They motivated their research participation: "*We are seen as one of the leaders in promoting climate change and supporting the scientific community. I always believe in knowledge and where it can take you. It's not mine but available for sharing, to utilise. It's a great asset but we shouldn't keep it to ourselves."*

7.4.10: Maritime Marketing, Tourism and Administration

Respondent II was typical of a smaller marine tourism/retail operator with considerable hesitation, needing more training/information, and unsure how to answer. Climate change was perceived as too remote, challenging and expensive to envision adaptation. Respondent 12, however, had taken measures:

> *"We haven't built within 30 metres of the mean high tide mark; we have upgraded our septic systems. We have invested in water tanks and pumps. We'd like to be able to invest in solar cooling/aircon for both guest comfort and staff productivity/health, but this isn't financially viable right now. We store large amounts of fish and other freezable produce in the event of shortages."*

Each cyclone season he prepared, at significant cost, with plywood boarding and tie downs, but was less prepared for temperature/humidity increases. He was concerned about changes in biodiversity/produce availability including from irreversible slow onset events like ocean acidification and major disruptions like storms. *"We have considered interaction with the Chamber of Commerce and other stakeholders."* Table 7.13 re-emphasises natural/physical engineering and other consistently favoured strategies.

Table 7.13: Marine Tourism, Marketing and Administration Adaptation Strategies

MSC Stage	Respondent	Adaptation Strategies (% Of Stakeholders Pursuing/Favouring Strategy)
Tourism Interviews	**II, V, VI, VIII, XXXIX, XXXIII LIV**	Information (66), Mitigation/Sustainability (36), Policy (36), Communication (30), Natural/Physical engineering (30) Technology (30), Risk monitoring (30), Training (24), Funding/Fiscal incentives (24),
Marine administration Interviews	**XVI, XXI, XXII, XXIII, XXXVII, XLVIII:**	Infrastructure/Technical Standards (12), Ecosystem, New Assets/equipment (12), Stakeholder Cooperation (12), Financial incentives (12), Marketing/Income Source Diversification (12),
Surveys	**13, 31, 40**	Other – leadership/capacity building (6), Cultural (6) Retreat (6)

Source: Author

Marine tourism's focus is to enhance the visitor experience and ensure sustainability through ecological conservation such as the Marae Moana Park and a former lagoon monitoring programme "*Management is key to ensuring our resources in marine sector can be safeguarded for sustainable tourism in future, given it remains key for marketing. It's not something we have to do – something we are doing to protect oceans".* It has prioritised research and data along with mitigation efforts to curb emissions. *"We have built superior, sturdier seawalls. We have to change what we eat, when we eat, our habits and lifestyles. Nature can be self-correcting if we refrain from worsening pressures."* The organisation is considering investing marine bioengineering to build higher islands, coral rehabilitation or start buildings city underwater/floating artificial islands, although the Cook Islands lacks current institutional capacity. It proposes the need for financial or legislative incentives for tourism operators to invest in climateproofing measures.

Respondent 54 favours coordination. All should be really active during a disaster, with a proper plan to ensure all have access to basic supplies, water, communications and electricity. Government should be aware of problems in delays, with back up plans to help local efforts. Operators would be helped to recover more swiftly with access to credit/loans and affordable cyclone /storm/drought relief insurance. For the future, he is not so concerned about climate change and considers some competition healthy; focusing on environmental sustainability and responsibility, with as much natural produce as possible.

Respondent 6 alluded to retrofitting resorts, shops and restaurants to be more cyclone-proof via the new Building Code. Businesses that invest in this should be rewarded, not just penalised e.g. tax deductions on improvements for resilience to storms or to decrease environmental impact, training, education and early warning systems. It suggests integrated climate data on websites, social networking, modern technology for communications, cooperation and information sharing, creating connected smarter ports and interdependent users electronically. To defend vulnerable biomes further, respondents suggested accessing conservation funding. Eco-tourism with higher profit margins and smaller visitor volumes could be more sympathetic over time, preserving reputations for marketing. It can focus on research and experiences.

Maritime administration (Respondents XXI-XXIII) focus more on lobbying international entities to mitigate emissions, targeting causes rather than effects. International technical standards introduced by 2020 are projected to increase vessel efficiency and lower pollution. The 100% renewable energy goal by 2020 is cited as evidence of domestic commitment to adaptation. However, they currently do not enforce emissions reduction and mitigation plans for existing operators, investors and communities, (either foreign or domestic). Aitutaki was mentioned as a backup airport/port but no supporting evidence was provided. Close relationships allow more congruent and coherent adaptation. Given staff constraints, a tendency exists to delegate regulatory powers to other individuals. Communication will be improved towards a single, centralised government information database, more user-friendly than diverse sources such as shipping manifests and policies. Interviewees mention the need for a Cook Islands emission paper with data i.e. how much is contributed per person per sector. They mention vehicles have no emissions tests locally. Plans, procedures and an alarm are proclaimed. However, the procedures may not always work. In Samoa only 7 minutes warning was received for the tsunami. So, psychology remains paramount.

Respondent 39 (marine tourism operator) indicates adaptation solutions such as learning from other Pacific countries. People need to start planning and making investment choices for the future, and listen to and engage with others in the industry. Video documentaries about different topics are effective. She feels not only limiting adaptation finance to governments and communities, would be the most efficacious form of adaptation. Businesses continuously experience needing to be self-reliant, lacking state assistance They need credit access and a moratorium for several months to recover before repayment. It could be limited to those established taxpaying businesses who were investing in taking precautions to be more resilient. It aids the challenge of getting businesses to prefer cost-effective practical solutions. Speed of release and action is crucial to avoid extensive impact consequences. Existing labour constraints have previously been overcome by rapid post-disaster labour mobilisation to pre-empt further damage costs and vulnerability.

Respondent 49 mentions technology aids in adapting maritime security via satellites and mobiles not just radio phones. More crew is being recruited to counter labour scarcity and crew fatigue with 13 available -12 are needed for a patrol. The unit is cautious, reactive to events rather than proactive at-risk monitoring and response minimising. They envision greater fisheries law enforcement challenges and physical protection are needed given past climateproofing failures. "*They built the breakwater but had surge heading onto wharf and took it out; backwash snapping mooring lines and massive wave surges for vessels." "Some of the rocks have to be removed".* During disasters they consider their role to be just a sea transport platform with their own areas of responsibility. They propose better intelligence and cooperation - not tapping into customs, immigration or transnational data. *"By the time information gets to us, it's too old to be useful. Agencies like to keep to themselves unless things get worse. By then it's too late. The message is clear for the public, be prepared. Tourism's biggest concerns are immediate but in reality, they could be stricken at any time."* Eco-tourism remains an alternative and to portray the islands as a boutique destination. The tourism industry has suggested underwater cobalt mining and related tourism may provide an alternative to a ravaged environment and climate.

7.4.11: Consumer/Communities

Respondents 24-27 indicate government investment in community awareness, training and infrastructure /ecosystem projects appears useful but they do not know how long it will last. They mention eco-tourism and aquaculture potential; installed water tanks for drought along individual initiatives. Respondent 24:

> "*Information needs to be put in simple language including using pictures and is appropriate to the context i.e. island responses and not examples from Africa or Asia. Government has built a cyclone shelter for each Northern Group island to provide populations with a place to reside in.*

Respondent 56 proposed engineering solutions to preserve coral reef and fisheries being polluted further. He designed a wastewater treatment <0.5 acres, avoiding land, environment; technology and geophysical constraints. This 4-storey 24 room resort integrated 15 KW off-grid solar power, clean water tanks and hydroponic garden terrace with zero waste discharge using engineering, technology and New Zealand design standards. The resort gets marketed under eco-tourism and climate resilience, enjoying 88-90% occupancy rate. It soon becomes economically viable at $250 per night. Limited business is present from customers for eco-efficient solutions Foreign companies cite fiscal constraints in adapting. Yet this retailer proposes $80,000,000 per year Foreign Direct Investment exists untaxed as revenue which could help pay for this.

Table 7.14 categorises favoured stage solutions. Respondent 29 advances commercial adaptation through improving funding and training via mentors relaying experience and business incubation. She proposes a decent commercial reserve fund for reputable businesses with defined guidelines on how to respond, better use of ideas, resources and cooperation. She recommends crop and fisheries diversification to avoid dependency or overexploitation of certain resources. While aid funding is available, oversight and monitoring was advised for programmes to succeed. Respondent 37 indicates communities adapted by relocating to caves during events. "*As much as we want to invest in good strong buildings, something as simple as a cave works."* She mentioned solutions ought to ensure safety, security and welfare, not just during immediate post-disaster but during recovery. Having condensed information summaries of effective, practical, tried and tested solutions is advised: "*We want to use technology affordable, sustainable and know who to go to".*

Table 7.14: Community/Consumer Adaptation Strategies

MSC Stage	Respondent	Adaptation Strategies (% Of Stakeholders Pursuing/Favouring Strategy)
Interviews **Survey**	**2, 3, 4, 5, 6, 22, 23, 25, 35, 36** **XXIV, XXVI, XXVII, LVIII:**	0 Communication (42), Stakeholder Cooperation/Information Sharing (35), Information (35%), Risk monitoring (35%), Financial incentives (35), Information, Physical/Natural engineering (35%), Sustainability/Mitigation (28), Legal (28) Policy/Planning (28), Infrastructure Technical Standards Ecosystem (28), Migration (21), Market/Income Source Diversification (14), Mitigation/Sustainability (14), New equipment/assets (14), Flexibility (14), Training (14), Technology (14), Other – Indigenous Knowledge (7), Elevation (7),

Source: Author

Respondent XXXIII recognises climateproofing advantages, but retrofitting to comply with revised Building Code technical standards inflates costs and is backward looking for past not future risks. Tourism cannot invest in hard coastal protection infrastructure as it produces adversative marketing effects and EIA requirements. Resorts cannot be elevated past two storeys. *"Nothing higher than the tallest coconut tree."* Most of the population will evacuate to Australia and New Zealand given inadequate people, skills, capital or outflows of goods. For the rest living under more arid conditions, existing to feed and support a new seabed cobalt mining community and their visitors, remain issues of economic continuation, social security and welfare. Local community needs would be prioritised last: "*The only benefits from mining will be royalties".* If this mining industry fails to transpire, under climate change tourism and general marine economy are guaranteed to shrink rapidly. There remain a minority of people who believe more extreme views: "*We've reached the tipping point that business cannot do anything about it. We might as well concentrate on profit and business as usual while we can. Resistance is futile."*

Respondent 48 illustrates water tanks, community education and enforcement as current solutions for droughts. Small mobile water monitoring equipment and desalinisation units aim to supplement limited freshwater lenses, especially for outer islands. They survey monthly water transfer rate to determine reserves and capacity, with plans depending on the level of severity: "*We get information from outer islands – number of tanks and holding capacity, estimated volume at a certain percentage".* Island Climate Updates occur, notifying communities when below normal rainfall is expected. The community monitor each other's usage, conscious of scarcity. *"Encourage them to monitor themselves and others – otherwise it's not effective and worth doing".* He considers there is no such thing as completely climate resilient crops, fisheries or marine resources, so stakeholders should protect what they have to avoid a welfare economy. Renewable energy is cited. He advises communities adapt with enough money to be resilient, a home upgraded to the new Building Code, water, energy and food self-sufficiency ensuring they are able to repair/build assets. He felt they were aware following training, but need visible examples:

> *They know of cyclones and frequent dropping levels of water and clearly linked to climate change. In the south, they're considering groundwater – repairing tanks, training and conservation of resources." "You have to ask yourselves as government whether it's really worth the effort keeping the island going." "When it rains –short but very intense for 1-2 minutes then start, then 3 hours later. You have to get the water while it lasts. We are slowly building holding capacity."*

Respondent LXVIII proposes ecosystem rehabilitation including climate resilient crop species for biodiversity and coconut seedling trials to provide extra water for droughts/heatwaves. They need to investigate whether emissions affect plant/species' growth, yields and nutrition, difficult without the right expertise and equipment. This aims to ensure domestic and export market consistency, especially during any disruption, providing crops for recovery. However, it is restricted to terrestrial supply chains as MMR do not provide the equivalent for MSCs. Hydroponics and organic agriculture/aquaculture are proposed as outer islands exports. Training is suggested as agricultural extension and marketing services are not visibly aiding communities. He advises needing 3-4 staff technologically accurate, proficient and understanding climate change, otherwise nothing will happen. This reduces pressure on wild fisheries and other MSC products for trade and food security.

Respondent 59 identifies climate change is inevitable and communities and individuals must adapt and survive They can show resilience is worth the effort and investment, but need the right leadership and decision-making. Psychologically this targets internal strength, character and experience, also valuing indigenous knowledge, with local cooperation securable via actual consultation and participation in solutions. She noted first they asked for fishing gear; second storage facilities and third outboard motors under a climate change outreach project. She prioritised women empowerment as key to adaptation. An ice machine sat unused for 2 years until women asked if they could take over its operation and maintenance. Those living with climate change daily treat their environment, community and lifestyle with more respect. It provides a way of life that does not just focus on the government and model of governance but on humans responding to no boat for 4-6 weeks, if stakeholders prioritise climate change adaptation.

7.4.12: Financial Sector

Table 7.4.15 conveys financial stakeholder strategies. Respondents 3 and 4 indicated an absence of specific stage adaptation examples. Respondent 7, while noted that physical assets had to be secured during events, but none had yet been damaged. He continued:

> "*Climate change is not a current Commission focus. Stakeholder interaction and consultation will be held when necessary. We will attend any meetings on this subject when possible. This is why our organisation has decided not to interact with other stakeholders over climate change."*

However, businesses are required to maintain quarterly reports, sufficient reserves, business continuity plans and backed-up data hosted at remote sites. This aims to restore commerce timeously, highly recommended to modify for climate change and to marginalise systematic risk. This must include training in a localised disaster risk management plan. For future events the stage expressed interest in other countries as other event locations influence local investment, aid and commercial flows. A challenge of looking into a climate change future lurks. "*Lucky a cyclone hasn't really affected the banking community. We're hoping to have proper guidance, a plan and resources when it does."* Respondent 44 mentioned elevating assets, shutters for ATMs, protect glass and sealing cabinets. Insurance exists for larger firms. Although products and services are unregulated, adaptation would be greatly strengthened if related insurance and commercial credit services were provided by the financial sector, for resilience, restoration and prosperity. This could link to PCARFI, the Geoportal and other risk data to form accurate cost estimations and risk perceptions. Ultimately advice remains *"Go back to basics and learn to live with what you need to adapt and prosper*."

Table 7.15: Financial/Insurance Adaptation Strategies

MSC Stage	Respondent	Adaptation Strategies (% Of Stakeholders Pursuing/Favouring Strategy)
Interviews **Surveys**	**III, IV, XLIII, XLIV** **7, 37**	Mitigation/Sustainability (71), Stakeholder Cooperation/Information Sharing (71), Training (71), Funding/Financial Incentives (71), Information (56), Policy/Legislation (56), Communication (42), Risk monitoring (28), Ecosystem (7); New equipment/assets (14), Retreat (7), Marketing/Income Source Diversification (7),

Source: Author

Respondent 50 remains concerned about uncertainty, favouring more research. *"We don't know what sort of data we need to make that decision. We need strong data to create a more sustainable future tailored specifically for each of us."* They remain concerned about the exact method and formula to calculate unique emissions. *"If you look at a Boeing 737, we can calculate fuel consumption rate, no. of voyages, vessels, speed and emissions level from A to B; there should be some sort of easy to use formula."* They express concern that even if they become emissions neutral; does it save much; does it allow the US another 100 tons/year or Australia to open a mine?

> *"One has to be realistic. Can a ship have 0 emissions? Can it go 100%? If Kiribati goes 100% renewable, it will not save them. Why should US worry about 200 people? We are worried because we are concerned about small communities? Climate change is still going to go on. The question is what is their refuge from a drowned homeland? Do they get another island somewhere or another state in Australia?"*

Communities question the sustainability of tourism, fisheries, agriculture, aquaculture and entire MSC's. "*You need to know where you are; get a whole picture of everything else before you can decide what to do and where to act. I can't control everything or everyone but I can control what I emit."*

7.5: CLIMATEPROOFING ADAPTATION STRATEGIES FOR PACIFIC MSCs.

The above individual adaptation solutions can be integrated as a series of strategies, capable of more effectively climateproofing Pacific and global MSCs. Section 7.5.1 shows funding as a core constraint consistently recognised by stakeholders. This provides further insight into resolving KRQC, ARQI and ARQII. Core strategies are highlighted below. This section outlines additional considerations when implementing strategies. It identifies the continued lack of international and domestic, private business, community and individual stakeholder risk identification and adaptation efforts. It proposes these are prioritised in adaptation plans and strategies. Any individual solution or overall MSC stage and system strategy should be evaluated by how much it has enhanced resilience, reduced vulnerability, preserved stakeholder requirements, ecological capacity and minimised disruption cost/accelerated recovery times. A risk event monitoring and review stage can assess these against projected existing and accumulated risk. It suggests providing standardised criteria to ascertain each asset, system, operation and ecosystem's potential vulnerability to climate change. The following key aspects of climate change adaptation are recommended and discussed below:

- Capital, Financing and Investment (Section 7.5.1)
- Climateproofing Infrastructure and Future Design Capacity
- Communication, Coordination and Media
- Ecological –Pacific Theory of Ecological Capital (Chapters 5/7.6.2)
- Education and Training
- Enforcement Capacity, Legislation and Policy – (Chapters 4, 7)
- Information Uncertainty -Theory, Equations, Empirical case studies,
- time series data (Chapter 5/Appendixes) and Chapter 4, Pacific Futures tool)
- Psychology – Proactive Risk Expectations Theory
- Technology

7.5.1: Capital, Funding and Investment

Cook Islands stakeholders identified a core adaptation constraint to climateproofing as limited private sector capital and funding access. Factors underlying their reluctance to invest for climate change are listed below. Specific information is required to effectively finance adaptation. Physical indicators are proposed measuring the extent to which an investment is effectively climateproofed. This is essential to consider how any investment is or will be influenced by these risks.

- Asset resilience under IPCC/Downscaled projections
- Conditional Probability of Failure, Timing, Intensity
- Extent of Vulnerability/Risk
- Event experience
- Impact Costs
- Implications for cashflow, gearing ratio, liquidity, solvency, profit, return on investment.
- P/E to growth ratio, P/cashflow, P/E ratio, Profit Margin
- Portfolio Exposure
- Projected Recovery Time, Projected Performance
- Opportunity/Inaction Costs
- Regulations, Taxes, Incentives and Penalties
- Targeted benefits, cost savings, revenue and opportunities

Existing research recognises this constraint but ignore these factors, (Investor Group Coalition Climate Change 2016). It aims to encourage uncertain stakeholders to become more proactive, recognising opportunities (section 7.6) and the need to effectively respond to risks and impact costs. Climate change is worth investing against, being more profitable, sustainable and preserving stakeholder requirements more reliably than the opportunity cost of inaction. These thesis-proposed indicators can validate investment decisions over alternatives, forming factors that require attention for business stakeholders to finance/invest in climate change. Appendix XII affirms through examples how climate change can be profitable.

Information Specifically Required for MSC Stakeholders to Invest and Adapt

- Asset resilience under IPCC/Downscaled projections
- Conditional Probability of Failure, Timing, Intensity
- Extent of Vulnerability/Risk, Event experience
- Impact Costs
- Implications for cashflow, gearing ratio, liquidity, solvency, profit, return on investment.
- P/E to growth ratio, P/cashflow, P/E ratio, Profit Margin
- Portfolio Exposure
- Projected Recovery Time, Projected Performance
- Opportunity/Inaction Costs
- Regulations, Taxes, Incentives and Penalties
- Targeted benefits, cost savings, revenue and opportunities

Physical Indicators Measuring the Extent to Which an Investment is Climateproofed.

- Business Awareness over climateproofing resilience
- Change in Asset Performance
- Change in Conditional Probability of Asset Failure/Asset Resilience
- Change in communication, financial, information, physical, psychological exposure and leadership
- Change in Percentage of Assets Exposed
- Change in Risk Perception/People trained
- Competitors
- Coordination/Cooperation with other stakeholders
- Demand/Supply/Market Changes
- Development of a Business Continuity Plan
- Extent of Mitigation/Adaptation Investment
- Extent of Globalisation, Asset Interdependency and Supply Chain Exposure
- Future Earning Power
- Liability
- Projected Risk/Vulnerability –Long Run/Short Run
- Recovery time changes
- Resources Allocated/Reserves
- Resource Sustainability
- Stakeholder Reactions/Reputation/ Requirements

7.5.2: Proactive Risk Expectations Adaptation Strategy for MSC Stakeholders

This strategy formalises a psychological approach to climateproofing MSCs and stakeholders. Recognising the significance of human risk expectations and behaviour on impact costs, it favours proactive intervention for effective adaptation. It considers why stakeholders do not prioritise adaptation. It advances a response strategy, utilising the above core strategies to motivate psychological willingness and behaviour change. It provides several techniques to rationally manage expectations for MSCs. The Proactive Expectations Theory proposes mainstreaming climate change risk management as one synchronised risk. Stakeholders should be legally bound to consider this Pacific approach across the supply chain, when registering, operating and creating a business. Access to historic risk data, awareness of the extent of public sector adaptation and future projections should be available. Optimal legislation would ensure stakeholders are responsible for local ecosystem defences, lowering vulnerability and increasing resilience where practically possible. Greater enforcement capacity would safeguard this with incentives to encourage greater mitigation/adaptation. Violations should be penalised. Based on the precautionary principle and scientific evidence, this seeks to overcome denialism, inaction and expectations, which solely rely on the public rather than commercial sector to proactively adapt. It overcomes market failure to estimate and prioritise climate change. The following psychological constraints present core factors indicating why adaptation is not prioritised:

MSC Psychological Constraints to Rectify

- Apathy/Indifference
- Asymmetrical Information/Uncertainty
- Character assassination –rather than evidence-based critique
- Despair/Haplessness
- Faith in others/Technology
- Fear of ostracism/Powerlessness
- Lethargy/Inaction
- Moral hazard
- Pedantry
- Present moment orientated –Short Term Immediacy Syndrome
- Risk aversion –the status quo
- Self-advantage/gain
- Self-interest

The first challenge is overcoming a refusal to recognise the problem. Aside from uncertainty over climate change and threats to ecological resources; the major threat is psychological. How humans react determines the extent of risk and impact costs. Beyond other factors, it influences the effectiveness of mitigation and adaptation. Yet the above psychological constraints have not previously been identified, integrated and resolved in climateproofing supply chains and stakeholders. Nor have they fully been developed and measured for evaluating impact costs. Cook Islands evidence and other Pacific adaptation strategies seek to overcome these constraints, which prompt inertia and stagnation for supply chains when contrasted with government sector efforts globally. From a MSC commercial perspective; stakeholder requirements, assets and resources will not survive under business-as-usual scenarios. Other risk management methods exist but not effectively for climate change.

Given these factors, modifying human behaviour presents a significant global challenge this thesis proposes for future research. Uncertainty and asymmetrical information are resolvable however, by producing simplified, local data and criteria based on Chapter 4 guidelines. Increasing stakeholder participation and awareness facilitates more accurate risk estimation for their perceptions. Offering actual methods and case studies emphasising how risks affect stakeholders personally and across a supply chain, can minimise apathy and lethargy. Considering risks could be conditional for investment and development. Assessing risk, vulnerability, extent of adaptation and systematic interdependency for individuals, partners and competitors provide empirical metrics as to whether having faith in others is a reliable climateproofing measure. The conditional probability of an asset/system failure from a specific event provides a second measure. More stakeholder involvement would promote personal interest, motivation and willingness to act. If solutions and opportunities are suggested, rather than obsessing over costs, they are less likely to feel despair, indifferent or powerless. If a formal policy is actively encouraged; fear of ostracism or loss of self-gain and self-advantage is diminished. Limited research has evaluated the feasibility, rate of investment return and consequences of technological alternatives including geo-engineering and carbon capture and storage. Technological progress is more uncertain than investments in measures that not only adapt but provide extensive co-benefits.

Over decades of risk research, few solutions incorporate changing human psychology and perceptions of risk, despite this influence. Other than experiencing an event and accessing information, training through simulated single and multiple events provides an effective adaptation measure. This can assess how individuals will psychologically react and prepare for any scenario type, (as undertaken for the Cook Islands). Climateproofing via psychology and expectations provides mechanisms to determine if business would resume normally. Self-interest needs to become part of this; especially since personal behaviour from a risk event not only affects the business and ecosystem but across the MSC. It can emphasise how expectations minimise maladaptation, impact and opportunity cost. It is more cost-effective, given increasing average and Black Swan risk event probabilities, than to await an event as a final test. Understanding actions and inaction presents definable consequences could prompt more environmentally and risk-sustainable behaviour. Hope, profit, empathy, ambition, responsibility and efficient resource utilisation facilitate productivity and far more probable survival. Effective information, participation and media communication of systematic risks and consequences can counter scepticism, particularly among developed nations. Decisive leadership and mass participation are pivotal, plus supporting successes for pervasive risk. These can more credibly persuade those uncertain or reluctant to change.

This theory considers stakeholders need realistic expectations viewing climate change proactively, to mitigate and adapt. This avoids reactive behaviour where disruption costs throughout all Figure 6.2 time phases are maximised, as psychologically many stakeholders are unprepared for climate change. Personal relevance promotes cooperation once they understand risk identification, which information to collect, which resources are necessary and what actions they can take. Stakeholders should recognise risks but value assets, assess impacts, understand and prioritise. Conventional risk management marginalises these psychological factors. Theory proposal fails if it does not reflect why stakeholders initially created the conditions necessitating the proposed strategy and why these conditions often remain. Stakeholders are frequently present-moment orientated, concentrating on risk events, costs and benefits within an immediate time horizon. Providing time-series data, probabilities and methods enabled them to concentrate decision making over greater periods. Risk aversion, apathy and inaction can be countered by further advising them how requirements will be affected plus inaction, maladaptation and opportunity costs. Ignoring psychology preserves the status quo of inaction and limited, reactive adaptation. Risk averse humans prefer certainty, despite significant impact costs, to the unknown.

Targeting psychological expectations and behaviour ensures any adaptation benefits become routine and permanent, not temporary. Moral hazard is marginalised with mutual cooperation, interest and adaptation. Indicating opponents lack empirical evidence can persuade others through common sense and reason. Inquiries could focus on their doubts, and what could convince them to react. To persuade people, climateproofing adaptation needs to indicate personal lifestyle, interests, employment, income and environment are far more secure and cost effective; than losing access when events occur. For those who have pursued adaptation – how many have actually regretted it? How many wish they had responded after a risk event? Theory needs to distinguish between producers, consumers, other stakeholders and public sector in adaptation. Stakeholders need to specify as much information, to replicate a scenario as accurately as possible and to link adaptation and experience to training and to coordinate across supply chains.

When climateproofing the projected reaction of each stakeholder influences the strategy's effectiveness on performance, resilience and disruption. Information, training and awareness lessens this risk. Currently they react with maximum disruption, focusing on other priorities. Many act post-event – those that survive. Focusing on recovery advised by conventional risk adaptation theory does not prepare stakeholders psychologically to effectively climateproof, invest in ecological capital and exploit other opportunities. Climate change needs emphasis over other more familiar risks, with conventional tools for risk reduction. Problems exist – but hope remains if action is prioritised. Interest needs sustaining so momentum is not lost. Effective information needs to be obtained and utilised over risks and impact costs. Stakeholders need clear cost-benefit comparisons of various adaptation strategies to understand self-advantage and self-gain convincingly. Their requirements and functions must be retained. Although not all human behaviour is certain to change, achieving these strategies provides greater inducements to persuade other stakeholders, given pervasive scepticism and urgency. Ultimately, reality will impoverish scepticism through attrition, failure and bankruptcy. Choosing uncertainty over stability of resources, revenue, infrastructure, expectations, supply chain activity and policy (favoured by the Pacific); will determine if these psychological constraints to effective climateproofing are less valid than this sections' theory favouring proactive expectations of climate change.

7.6: CLIMATE CHANGE FUTURE OPPORTUNITIES AND IMPLICATIONS FOR OTHER NATIONS.

As previously detailed, many solutions are mitigation or adaptation orientated. Ignoring climate change will be costly for future business, in squandering competitive and other advantages. This research's conceptual contribution considers adaptation through climate proofing advantages and future opportunities outlined below and in Appendix XI. The future of global MSCs among projected climate change should follow the Cook Islands example as an exploratory case study, exploiting emergent business opportunities. Equally, the Cook Islands can learn from other nations. The successful stakeholder will invest in long term horizons. The concept behind proposing these opportunities is to prompt stakeholders to prioritise action. Supply chains and individuals must progress beyond reactive post-event behaviour noting it remains ultimately unproductive to favour extractive growth destroying future trade. Unless these opportunities and others are prioritised; global supply chains will be challenged to ensure an IPCC, 'business as usual' scenario future.

Advantages of Climateproofing

- Augmented Resilience, Lower Vulnerability.
- Business Continuity, Resource Security.
- Experience.
- Publicity.
- Lower Disruption Costs and long-term cost saving.
- Sustainability, efficiency, quicker recovery time.
- New markets/services/products/ greater market share/enhanced competitiveness.
- Greater probability of survival.
- Pre-empting regulatory anticipation.

Climateproofing Supply Chain Opportunities.

- Aid/ FDI/Remittances.
- Aquaculture, aquaponics.
- Climateproofing Infrastructure and equipment investment.
- Credits for mitigation and adaptation, venture capital and incentives.
- Export/Import power.
- Experience, Psychology and Training.
- Green Economy –climate bonds, emissions credits.
- Localisation rather than globalisation.
- Pacific Ecological Capital and real estate.
- Reputation and publicity.
- Reserves; Technology.
- Trade diversion, continuation and creation into new markets.
- Traditional crafts, resources, products and techniques.

The Pacific Ecological Capital Theory of Climate Change Risk Management

Conventional ecosystem adaptation focuses on system restoration not proactive capacity. It ignores the need to integrate a supply chain for effective risk management, future survival and prosperity. Existing risk management theory has ignored how ecosystems stabilise risk for maritime and global supply chains most effectively, ensuring resource security and asset resilience. This thesis's risk-analysis incorporates these risks for Pacific and global MSC stakeholders. It proposes implementing a new Pacific theory of ecological capital based on Table 5.2 requirements. This secures and invests in MSCs via maritime ecosystem restoration and conservation, minimising environmental pressures from human externalities. Oceans cannot remain exploited permanently, a waste repository undervalued with cheap prices. Risks cannot be trivialised. It proposes developing ecological economics to preserve subsequent MSC stages and resources. Enhancing natural capital/resource values through long-term sustainability, converts risks into opportunities. Pre-emptive action also minimises insurance loss and other potential impact costs.

Just how necessary and indispensable is the Pacific MSC system to its businesses, given impact costs in Chapter 6? Without securing the environment and ecological capital access in the short, medium and long-term, stakeholders will not need to worry about climate-proofing operations, assets, technological systems and infrastructure. Given existing development challenges and scarce resource constraints, others (especially international/local communities, consumers and businesses), cannot afford to rely on government but must invest in marine ecological capital, literacy and education. This preserves their own operation and supply chain survival. To minimise expenses, they can utilise existing environmental/climate change information for risk assessment; using coral reef and ecosystem monitoring from the Cook Islands Ministry of Marine Resources/other sources; whilst partnering with those experienced.

Ecosystems as ecological capital also represent climate change opportunities for global and other MSC stakeholders. They enhance land asset value through functions/preserving coastal developments. Coral reefs, sand accretion and foreshore vegetation actually produce land over time, avoiding coastal erosion with reef calciferous sand to purify salinity. Afforestation provides commercially sustainable resources in biodiversity and possible eco-tourism. With ecological reserves, participants can claim carbon offsetting, tax and market credits. Conserving certain species facilitates resource security, enabling purity, quality control, prosperity and survival against climate change risks. Indigenous knowledge, patent and technology development can be utilised and future research can consider natural asset values; especially in food, materials, art and pharmaceuticals. It can assist in promoting commercial production of marketed/ornamental species once ecosystems recover, avoiding full exploitation of oceans.

From 1980's-2000 the Cook Islands pearl industry collapsed due to neglected investments in maritime ecosystem. This could be revived, marketing purer pearls then synthetic. Pa-ua, despite being an exported quality product, declined dramatically from historical exploitation, without thought of investment. Despite the demand it received a Cook Islands export ban aiming for species recovery. This provides a rare ecological resource example worth preserving and investing in. Similarly, high value resources threatened include the black lipped pearl oyster, trochus, rare seaweeds, coconut crab (a nearly extinct local delicacy) and exotic corals. Game fishing and marine tourism provide further opportunities, once ecosystem reserves recover. Gene banks and resource sanctuaries should exist locally for global research and biodiversity, both naturally and in reserves. This ensures opportunities remain rather than facing avoidable extinction costs. Resource risk management represents a comparatively minimal investment in initial and operating costs, versus the significant costs of losing ecosystems for Pacific and global supply chains.

How would an ecosystem affect land/asset values or coastal exposure for MSC assets if removed or collapsed? What is the opportunity cost of land and species extinction? The world's oceans have been over-exploited and under-monitored for climate change risks and resource or food security potential. Given moral hazard and free-rider problems, weak monitoring/law enforcement for fisheries and existing overfishing pressures; oceans, lagoons and reserves may in time require rare species. Historically, ecological capital has proved the best in preserving capital asset, operation and performance against fundamental climate risk through forethought of investments, internalising externalities. Given projected increases in event frequency, duration and impact cost intensity, ecological reserves provide profitable investment horizons in short and long term. It reduces volatility and uncertainty loss, providing higher rates of return/profit on investment than comparable low interest/high risk, financial services. This occurs especially when considering property values, licensing, intellectual property, resources, tax minimisation, lack of existing regulations, publicity and species migration. Diversification minimises risk and resource dependency on others. It ensures MSCs remain profitable, usable and ecologically sustainable. Providing resource reserves ensures swifter recovery. It enables opportunity against unprepared competitors. It ensures utilisation, risk security and minimisation for maritime and other supply chains/individuals. Climate change externalities can be reduced through ecological rehabilitation, asset preservation and carbon offsetting for mitigation.

It is illogical to ignore this fundamental unconsidered and underestimated risk, currently multiplying across the supply chain, ecosystem and environments. Ecological capital risk management could concentrate on preserving species, islands and offshore areas of the greatest biodiversity, risk, ecosystem function and market potential value. Weaker ecological capital has been shown to affect other supply chains and other components of a Pacific MSC. Investments also provide potential to preserve and market scarce products, e.g. the Cook Islands produce trochus and pearls for which a comparative advantage exists, aiding profits and local community simultaneously. Technology, products, training, climateproof infrastructure, capital equipment and waste minimisation efforts become more eco-efficient. Improving species resilience and environments offer further risk opportunities with potential to save/invest in Pacific or other vulnerable, coastal ecosystems, before they disappear or become uninhabitable. Consider coral reefs, beaches, mangroves, swamps, afforestation, estuaries, seagrass, volcanic fertile soil and species biodiversity. Each have functions, value and the potential to enhance or preserve existing asset and system values. As climate change increases, they become increasingly rare, valuable and vulnerable. Yet, supply chain interdependency increases risk. Decreased ecological capital loses the value of aid and foreign direct investment, as future MSC risks. These risks are comparatively cheap to offset/invest in, but expensive in impact costs; as events are projected to multiply. No technologically feasible, efficient and cost-effective equivalent to climate change risk management in climateproofing exists, without considering an ecosystem and its multiple functions.

Future research should concentrate on unique risk implications for Pacific stakeholders and ecosystems for commercial resource security. Specific location, ecosystem and supply chain, risk type consequences differ; yet have been ignored. Increased landslides multiply soil sedimentation, coastal erosion and species habitat loss. These present fewer maritime risks than tsunamis, wave energy, floods, cyclones and droughts to coral reefs and more fragile maritime species assets such as algae, trochus and black lipped oysters. Seabirds, crustaceans, reptiles, fish and mammals possess limited adaptive capacity with sufficient warning for sudden risks. Certain physical, economic and environmental constraints prohibit permanent adaptation to long term risks; without sufficient prioritisation and investment in climateproofing ecosystem functions.

Existing risk management theory overlooks how ecosystems stabilise risk for maritime and global supply chains most effectively, ensuring resource security and asset resilience. This risk-analysis considers Pacific and global MSC stakeholders implement a new thesis-proposed Pacific theory of ecological capital based on Table 5.5 requirements. This secures and invests in MSCs via maritime ecosystem restoration and conservation, minimising human-induced environment pressures. Without preserving a functioning ecosystem, globalised supply chain pressures of outsourced components, economies of scale, minimal reserves stockpiled, just-in-time production/and low sea shipping, transport costs; will be adversely affected. It proposes developing ecological economics to preserve subsequent MSC stages and resources. Protecting and enhancing natural resource values through long term sustainability converts risks into opportunities. Pre-emptive action also minimises insurance loss and other impact costs. Cook Islands funding, mitigation and adaptation efforts have primarily concentrated on climateproofing key infrastructure including ports, airports, roads and utilities. Capital and efforts should now be directed towards the ecosystem. This ensures future resource and maritime economy security, given existing climate change and non-climate change pressures. The Cook Islands and other Pacific maritime economies' survival capacity, markets and import demands increasingly depend upon maritime resources. Physical assets represent wasted investments, if stakeholders have no ecosystems to provide resilience, vulnerability and economic activity to support them.

7.7: SUMMARY

This chapter addresses disruption risks, providing a case study with empirical evidence for Chapter 8's final conclusions. Globally very few businesses are able to effectively secure supply chains against climate change. Private sector adaptation is frequently marginalised in favour of government initiatives, despite limited resources. Stakeholders should coordinate solutions, considering lessons from the South Pacific's experience. Climate change events still occur with consequences. Despite over 35 years' research experience, awareness and prioritisation for the South Pacific, it is essential to consider why risks remain. Why do projected impact costs multiply; despite repeated event exposure? Given impact costs, what previous solutions exist? Which are the most significant and successful adaptation strategies and why? Can adaptation solutions be applied strategically to other stage stakeholders, across a supply chain, risk types, time horizons, scenarios, commodities and locations? What is necessary to ensure business as usual?

This chapter outlined climateproofing adaptation strategies for the Cook Islands in answering KRQC, ARQI and ARQI. It presented the Cook Islands example as one of few nations to invest in a more certain future for its ports, shipping and MSCs. Five cyclones in 2005 contributed over $30,000,000 in direct economic impact damage to ports, shipping, crops and fisheries. Unlike most developed world and emerging economy, supply chain stakeholders, the Cook Islands ignores conventional risk recovery and management practises. In response to projected increases in global and regional, risk events it prioritises climate change adaptation and mitigation throughout all islands. This climateproofs stakeholders throughout a MSC. Given reputational, physical survival and other risks of collapsing MSCs, economies and ecosystems the Islands have integrated climate change and disaster risk management throughout political, social, economic, media, education, health, aid, environmental, cultural and infrastructure priorities. It has joined other Pacific nations in ratifying all related, international legislation and seeking action. However, contributing only 0.00014% of Earth's emissions its efforts to pursue the global preference for mitigation are constrained, until other stakeholders including businesses, media, government and individual consumers start taking climate change seriously and really strive to reduce emissions.

The Cook Islands recognises climate change both initiates new risks and amplifies existing environmental pressures and constraints of finite resources. Businesses are legislated to prioritise climate change risks and future sustainability, survival and emissions reduction, as conditional on aid. The limits of most MSC stakeholders and small island, developing states in mitigation, adaptation and migration proposes a future research and investment direction through the Ecological Capital Theory. This converts risk management into risk opportunities through investing in ecological rehabilitation and economics. Unlike other nations, stakeholders indicated they do not accept an uncertain future for Pacific and global ports, shipping, MSCs and world trade in ignoring fundamental risks.

In response to these and other risks the Cook Islands borrowed $100m to climateproof key infrastructure through a port expansion and modernisation process, increased research, specialised training, information sharing and stakeholder coordination (ADB 2014). It seeks to convert climate change risks into opportunities. This both acquires aid funding to support key infrastructure investment upgrades and also ensures its operations, people, maritime/land resources and economic activity are more resilient. It considers climateproofing an investment in the future, and provides complementary short/medium-term advantages of increasing, sustainable production, more efficient processes, reduced congestion and delays. It offers an improved quality of life and economic/social development over other nations and stakeholders. PCARFI (2015) proposes opportunities exist in exploiting indigenous knowledge and experience. Converting economies, infrastructure, systems and resources minimises disruption risks. Effective climateproofing adaptation must consider how each supply chain stage, business and stakeholder impacts Pacific MSCs, how to minimise them, and how stakeholders historically responded and swiftly adapted to emergent risk.

CHAPTER 8: CONCLUSIONS, LIMITATIONS AND RECOMMENDATIONS

8.1: INTRODUCTION

Climate change uncertainty threatens future physical, personal and commercial survival with accelerating collateral costs. As noted in Chapters 1 and 2, although stakeholders, stages, individuals and communities in maritime supply chains (MSCs) have great concerns about climate change, their risks have not been well considered and managed. This thesis aims to investigate the impact of climate change on Pacific MSCs and stakeholder adaptation strategies. It seeks to identify physical and economic impact costs, uncertainty and challenges caused to the region using Cook Islands as a case study. The study has discovered how interdependent stakeholders, community and industry remain on maritime resources, ecosystems and trade. This chapter presents thesis conclusions and summary of findings in response to KRQ's A-C, ARQI and ARQII. It illuminates existing research gaps along with theoretical, managerial, policy and other implications for stakeholders. Specific aims exist to minimise disruption risks, associated impact costs and adaptation constraints. The study method, findings and climateproofing adaptation limits are identified with recommendations to assist future research.

8.2: SUMMARY OF THE RESEARCH FINDINGS

To understand potential climate change implications for Pacific MSCs in general and the Cook Islands in particular, this thesis raised 3 core and 2 auxiliary research questions.

8.2.1: KRQA: 'What are the current and projected, disruption risks for Pacific Island MSCs, from climate change consequences?'

A literature review in Chapter 2 affirmed that while affirmed climate change presents a real and emergent threat, it has not been previously analysed for maritime economies. Research gaps were identified regarding:

- the risks and impact of climate change on specific Pacific ports,
- the unique impacts, risks and solutions for shipping and MSCs.
- The impacts on customs, access to maritime finance, and port pricing.
- The need for and impact of changes in legislation and policies.

Only a few developed/emerging economies or empirical examples exist for supply chains. In light of significant research gap this thesis is motivated to preserve core stakeholder requirements and performance. Chapter 3 established the need for a mixed method approach via a risk-vulnerability sequence; incorporating qualitative, stakeholder content analysis and quantitative risk probability/impact cost analysis.

Existing constraints in climate change risk, adaptation and action included the complexity of aggregate global scientific projections in determining specific risks. To resolve this, Chapter 4 provided a Pacific Climate Futures Tool and screening criteria so localised consequences can be determined for MSC dependents. This reduces uncertainty among various IPCC scenarios, risk types, stakeholders and supply chain stages. Main projected climate change consequences for the Pacific include:

- Rates of land and sea surface temperature rise at a rate slightly lower than the global average, based on higher thermal ocean expansion absorption, as small islands.
- Projected Pacific SLR is likely to exceed the current global average rate of 3.2 mm per year. This increases the predicted probability of flooding, increased wave energy and sedimentation, eroding existing coastal and engineering protection.
- A projected increase in heatwaves. The recurrence intervals of temperature maximum days are expected to increase. This increases the probability and associated supply chain, disruption costs of heatwaves and lower productivity.
- Annual mean wave height increases are projected from increases in wind speed throughout the South Pacific Ocean. These may increase physical risks to vessels and the probability of flooding, creating storm surges to coastal economies, infrastructure and ecosystems.
- Projected growth in ocean temperatures, regional pH balance and salinity from a 0.1 increase (1900-2000) to 0.3-0.5 by 2100. Increasing ocean acidification threatens the natural coastal protection and maritime resource functions of coral reefs and other maritime ecosystems. It increases the corrosion rates of vessels and coastal infrastructure, increasing maintenance and repair costs for stakeholders.

To adapt further, stakeholders should utilise existing data observations to project regional climate change but also focus on individual island projections. For the Cook Island case study, stakeholders will have to adjust to between 0.5-1.5°C by 2030, 2-5°C, 0.5-1.5m SLR and 5-8% precipitation increase by 2090.

The results of the case study in Chapter 5 initially verified the 7-stage risk-vulnerability framework through 59 interviews and 40 surveys with a 37% response rate. Results appeared consistent across stakeholder categories, education, experience and number of years the business was formed. Marketing, Tourism and Administration comprised the highest proportion of respondents (17%). The findings determined the significance of stakeholder risk perceptions as influencing the extent of awareness, impact costs experienced and adaptation. 62% of participants identified wind velocity as the most significant long-term risk, followed by coral bleaching (58%) and precipitation (52%). However, 88% thought drought, 99% cyclones and 34% gales were the most significant short-term risks.

Triangulation of results provided the first complete, time-series data for risk events from 1900-2015. Cyclones were historically most momentous with 33% of recorded events. 27% were storms. Thesis appendices provide further corroboration of results, ascertaining the increasing significance of climate change events for Pacific MSCs in frequency, duration and intensity. This validated Chapter 3's conceptual method approach of providing historic and future conditional probabilities for a specific risk event to occur in any given year, as a more accurate indication. For example, the minimal expected probability of a tsunami occurring in 2019 is 0.041. Without this approach stakeholders would have been more susceptible to underestimating or overestimating particular risks, e.g. overestimating droughts as a future risk, being only 2% of historic events. Qualitative content analysis identified local stakeholders perceived themselves well aware of climate change awareness, impacts and solutions. Many relate the incentive of actual experience as inducements to adapt from 1987, 1997 and 2010 cyclones, with 5 in 2005.

8.2.2 KRQB: 'What are the economic impacts of climate change risks on the future of Pacific Island MSCs?'

The results in Chapter 6 recognise the maritime economy is vulnerable, comprising 62.5% of Cook Islands GDP and 44.1% of employment directly. Costs are conditional upon risk type including Storm, Flood, Bushfire, Cyclone, Drought, Gale, Heatwave, Landslide, Earthquake, Tsunami and Volcano. Qualitative analysis of stakeholders' interview and survey feedback revealed the economic impacts of climate change on maritime economies; especially small island developing states. The minimum, historic impact costs across the Cook Islands MSC for 2005 cyclones, adjusted to 2018 values, was nearly $30 billion. Stakeholder content analysis further identified 56% of stakeholders experienced at least one impact cost type. To answer

KRQB in 2018 the study estimated future climate change as costing approximately a minimum of $139 billion. Stakeholders can no longer afford to ignore climate change risks and impact costs if aiming at business-as-usual. These findings emphasise how impact costs multiply across a supply chain, beyond official aid, media and government estimates.

8.2.3. KRQC: How can key supply chain stakeholders adapt to minimise the impact of climate change on Pacific Island MSCs?

Climate change is envisioned as requiring proactive actions to anticipate possible risks and costs. This involves minimising emissions and continuously evaluating risk as conditions change, rather than reactive post-event responses. ARQI: asked 'What are possible climate change adaptation solutions for Pacific MSCs?' A multitude of possible strategies for each MSC stage and sector were identified in detail by stakeholders as detailed in Chapter 7. For example, the marine tourism business sector favoured coral reef ecosystem rehabilitation, climateproofing fiscal incentives and modern technology such as artificial islands/underwater habitats. Stakeholders in general preferred information and research, mitigation and environmental sustainability to enhanced risk monitoring as the most potent solutions.

ARQII asked: "What are the specific constraints/barriers to developing adaptation strategies for climate change?" 63 respondents determined uncertain information and shortage of accurate, effective research as the most significant constraint (12% of total). 54 perceived psychological reactions (11%) and 51 geophysical/environmental limits (10%). 4% indicated cooperation with other stakeholders as problematic. Unexpectedly only 33 noted funding, recognising how many potential investment opportunities exist. The scarcity of holistic, climateproofing adaptation strategies for MSCs in existing research, and the need for specific legal and policy guidelines targeting transport and supply chains was identified in Chapters 2 and 4. This further affirms the theoretical contribution of Chapter 3's integrated methodology by evaluating the extent of capable adaptation. Estimated impact costs in 2005 for five successive cyclones was $29 billion. Total minimum, verifiable adaptation costs experienced equal $315.6 million. This indicated how comparatively cost-effective adaptation is. Climate change is envisioned as requiring proactive actions to anticipate possible risks and costs. This involves minimising emissions and continuously evaluating risk as conditions change, rather than reactive post-event responses.

8.3: RESEARCH SIGNIFICANCE, THEORETICAL CONTRIBUTION AND IMPLICATIONS FOR MSC MANAGEMENT AND POLICY

The thesis's significance and innovative contribution to knowledge includes recognising climate change as the most uncertain and emergent threat to future business, maritime economies and seaborne trade. The current study including research design, Cook Islands field trip, qualitative and quantitative analysis using primary and secondary data, and the analysis findings, provide an insight into the issues and challenges facing the community and stakeholders in Pacific MSCs in protecting themselves from climate change impacts. The findings go beyond those of studies based on secondary data without direct communication with the local community and stakeholders. Thus, the study's key contribution is better awareness of the vulnerability, challenges, and understanding of climate change impact and adaptation solutions for MSCs; (especially in the Pacific region). To carry out field research, the study has proposed a conceptual framework for MSCs to interlink climate change risk management with impact cost analysis, overcoming existing literature gaps. It validates field research as an effective method to gain greater insight into climate change uncertainty, from participants mainstreaming and prioritising risks.

This research's impact has further contributed towards enhancing stakeholder resilience, reducing vulnerability, ensuring commercial and ecological survival. It clarifies the consequences of not responding to climate change and simplifies climate change complexities for commercially orientated supply chains. The study presents an example of existing risks to prepare others for low probability, high impact events. Stakeholders need data to understand or realise certain impact costs are generic. Other costs are risk-specific, regardless of factors affecting impact cost magnitudes. This simplifies identification, calculation and responses in answering specific impact costs. It will aid in pinpointing cross-sectoral, stage or system impacts, and consideration not just of existing output/costs but future design/optimality. Once informed, stakeholders can better assess the personal implications of climate change and whether or not they are sufficiently prepared.

From a research perspective, the study has substantiated the need for a more comprehensive series of systematic, climateproofing adaptation strategies summarised below in terms of information/ scientific uncertainty, legal, funding, eco-capital, and psychological. These specifically target the quintessential constraints to existing global and local mitigation and adaptation. It creates major managerial policy implications for stakeholders to prioritise climate change regarding the cost-effectiveness, profitability, sustainability and other opportunities, adaptation presents. It also aims to minimise disruption and opportunity costs by providing methods and increasing familiarity with projected risks, impact costs, adaptation strategies, funding, legal and information resources. Theoretical contributions include.

- **Information/Scientific Uncertainty** (Chapter 4): Assessment and management of Pacific time series data of historic risks, Pacific Climate Futures Tool and screening criteria to evaluate climate projections/research, including accuracy, credibility, flexibility, consistency, autonomously verifiable, comprehensible, relevant, simple, equitable, robust, practical, generalisable and satisfying stakeholder requirements.
- **Legal:** The need for international regulations mandating climate change and disaster risk management mitigation, preparation and adaptation for governments to protect their people, businesses and MSCs.
- **Funding/Investment:** Identifying factors needed to climateproof physical investments and commercial opportunities presented by climate change. These are more profitable than emissions intensive, extractive growth encouraging disruption risks to supply chains.
- **Pacific Theory of Ecological Capital:** The future of Cook Islands/Pacific economies, survival adaptive capacity, markets and import demands depends increasingly on marine resources. Without preserving a functioning ecosystem, globalised supply chain pressures of outsourced components, minimal reserves stockpiled, just-in-time production, economies of scale and low sea shipping, transport costs will be significantly affected. Given existing funding, mitigation and adaptation efforts have primarily concentrated on climateproofing key infrastructure; capital and efforts for the Cook Islands can be directed towards natural engineering. This thesis's theoretical contribution recognises the importance of effective risk management for an entire supply chain and ensuring future resource security, given existing climate change and non-climate pressures. The ecosystem provides numerous economic advantages and opportunities to finance adaptation, insufficiently recognised in existing research. It requires a holistic view and approach to promote regional resilience and sustainability.
- **Proactive Theory of Risk Expectations:** The findings show psychological expectations remain the most fundamental barrier as to why MSC stakeholders are so reluctant to prioritise climate change locally and globally. A systematic literature review and results project South Pacific nations as among the more vociferous and physically effective stakeholders at mainstreaming mitigation and

climateproofing. They remain more psychologically prepared than global nations experiencing low probability, high impact events. Experiencing impact costs and concentrating on emergent risks over decades, has prompted action and investment. This potentially enhances future resilience, reducing vulnerability and supply chain interdependency.

8.4: STUDY LIMITATIONS

This study encountered several challenges and limits potentially influencing the accuracy, validity and generalisability of findings to other affected MSC stakeholders in the Pacific and globally. As an exploratory study, it found few comparable existing studies on climate change, risk management and MSCs/maritime economies. The proposed risk-vulnerability process, impact-event tree, cost analysis, conditional probabilities and qualitative stakeholder content analyses as a conceptual framework cannot be tested as more effective climateproofing strategies against others. Nor can findings in forecasting climate change or impact costs be easily comparable to other approaches. Existing sources are primarily qualitative, measuring risk perceptions rather than actual risk events. They provide generic, aggregate costs, compared to this thesis's refined, downscaled localised approach to ascertain personal impact costs. They could not include all the key supply chain stakeholders, indirect, intangible and ecosystem costs and effectiveness evaluation criteria, drastically underestimating true climate change impact and adaptation consequences.

Other limits include a scarcity of existing relevant data that can more accurately answer KRQs. As an exploratory study it pioneered many techniques and information sources to obtain data. It devised conditional probabilities for forecasting climate change and a centralised time series database of related risk events. However, calculations remain constrained by climate change uncertainty with multiple variables. Low probability, high impact, Black Swan events remain challenging to forecast against historic and future risks. Results indicate a minimum rather than actual estimates. Records and stakeholders provide incomplete, partial, primarily qualitative descriptions, which need to be amended. Stakeholders often lacked records or memories. Many were concerned that commercially sensitive information might potentially benefit competitors, despite the researcher pledging confidentiality and ethical conditions. This reduced the capacity to establish conditional probabilities of an asset/system failure from a specific risk event, as in Chapter 3.

Although the method aims to be generalisable across other Pacific locations, risk types and stakeholders, the study's findings are mainly limited to the Cook Islands. Time, budgetary, communication and information constraints prevented developing comparable regional case studies. It primarily calculates costs for five 2005 cyclones as the most accessible and influential source of information. Stakeholders experienced challenges in providing actual impact costs, given a lack of information and significant time lapses since the most recent events (2009 tsunami and 2005/2010 cyclones). For marine ecosystem fluctuations it remains challenging to distinguish climate change from other environmental/human factors. One field research challenge was non-responsiveness from invited participants, despite frequent reminders and efforts. A Blue-Sky Pacific bushfire interrupted emails, faxes and telephone satellite connections for several weeks, hindering stakeholder recruitment. Time and resource constraints existed for the thesis, with field research limited to three weeks, 59 interviews and 40 surveys, despite significant interest and willingness of stakeholders to participate.

Past chapters summarised literature, theory, method and results limitations. Being primarily qualitative based, the stakeholder content analysis may experience research bias based on perceptions, experiences and qualifications. A limited sample for each stage simplified data collection but created potential selection bias. Whilst findings remained consistent across demographics and supply chain stages, certain core stakeholders declined to respond or participate. Many individuals, fisherfolk, small businesses and communities mentioned time, opportunity costs and other priorities. This limited available data and method applications incorporating the extent of climate change risks, impact costs and adaptation solutions across an entire supply chain. International stakeholders were even more reticent, having not personally experienced climate change, nor recognising its potential significance. As Chapter 2 discovered, few climateproofing adaptation or mitigation projects ever conduct monitoring and review stages to determine success or failure. Since 1997 (for Manihiki Island), 2005 (Rarotonga) and 2010 (Aitutaki) the Cook Islands has not experienced related events. This creates study limits in determining how effective existing and advocated strategies will be in 'climateproofing', enhancing resilience, lowering vulnerability and cost. Maladaptation and opportunity costs remain expensive. Ultimately costs remain dependent on unpredictable events and human psychological reactions.

8.5: RECOMMENDATIONS FOR THE COOK ISLANDS AND FUTURE RESEARCH

Research found that whilst the Cook Islands and local MSC sector were generally well aware, prepared and acclimatised to climate change consequences, the sectors least climateproofed were the finance sector and those stakeholders whose headquarters were situated outside the Cook Islands. Major findings revealed core challenges to be psychological, funding and ecological with scarce resources and lack of effective, proactive leadership. Arising from these it is recommended that:

a) The Cook Islands enhances institutional capacity, markets more overseas and evaluates climate resilient species/coral rehabilitation, given MMR are not considering future adaptation proactively.
b) Leadership convenes a joint forum of ecological experts, producers, farmers, government, consumers, tourism, wholesalers, financial sector, retailers and marketing. This could determine a joint future and share experiences/concerns to avert a historically declining maritime industry.
c) Stakeholders with headquarters elsewhere should be specifically targeted to raise awareness and encouraged to make appropriate climateproofing strategies for adaptation and resilience.
d) In particular, the finance and insurance sector should mobilise resources for climate-related risk events including provision of emergency loans to local businesses to speed up recovery post-event.
e) The findings should be shared with other Pacific nations to consider if the results are transferable to their particular situation.

To overcome the above research limits, the following directions and recommendations for future research are proposed to extend this study's methods to other Pacific, Caribbean and global regions for comparisons. This aids in overcoming asymmetrical information and data limits.

- The values of personal recruitment and a field research method. The author presented and distributed surveys at the Cook Islands' Ministry of Marine Resources and to public community stakeholders at the University of South Pacific campus. The Ministry assisted in coordinating participants and a venue/IT access. MP's were addressed at a Parliament workshop/lunch and hearings related to the Maritime Zones and Marine Resources Bills. Professional associations including the Chamber of Commerce, linked to the Pearl Farmers' Association representatives and the business/tourism industry were addressed. One walked in the rain/wind and humidity/heat, tracking down non-respondents.
- Tactics to enhance the response rate, aside from media exposure, emails, phone calls and personal visits include asking stakeholders for key-informant referrals. Several phoned, drove the researcher to their offices or indicate them as an informal means of recruiting via peer networking. One appeared on local radio, Cook Islands Herald and television; retaining the broadcast and article copy to maximise research exposure. Introductions were made to local community members, shops and markets to informally recruit more participants. The entire circumference of Rarotonga Island was walked, physically examining coastal environment resilience and vulnerability of core assets and infrastructure.

- Future research can extend the above techniques, theoretical and methodological framework to other Pacific and global MSCs, for other climate change risk types, scenarios, time horizons and stakeholders. This would enhance the accuracy and generalisability of this framework, research findings and assumptions. Additional stakeholder recruitment minimises survey and selection bias.
- The above unique research contributions and theories can also be applied to other supply chains, with empirical evidence especially developed versus developing economies.
- As more information becomes available, qualitative and quantitative results can be calculated and triangulated for greater accuracy and reliability. Existing method stages can become more robust, comprehensive and effective as climate change decreases in uncertainty.
- Future research can assess if projected adaptation strategies are effectively climateproofing against emergent risk and whether awareness influences the extent of potential risk exposure and impact costs. Climate change's influence on key performance indicators and stakeholder requirements can be critically examined. This determines if stakeholder risk perceptions and awareness are sufficient to mobilise action or whether experience is necessary.

In conclusion, this research aimed to address how aware, resilient and vulnerable Pacific MSC systems, stages and stakeholders are to current and future climate change risk events. Future research methods can therefore prioritise the extent to which risks, impact costs and adaptation strategies can be effectively determined not just for the Cook Islands but for other South Pacific MSCs and economies. Current risk management merely considers existing scenarios as the extent of maximum possible risk, underestimating worst case examples. It depends on stakeholder risk perceptions rather than measuring historic risk through time series data for future risk. Long-run equilibrium assumes constant growth rates, a supporting population, functioning economy and resources able to effectively monitor, respond, identify and adapt to risk events over time, ignoring climate change which infers risk adaptation and resources are sustainably secured. Providing evidence and insight from those who have experienced climate change and proactively reinvested; can mobilise others to respond and reciprocate. This will empower individuals, businesses and communities to more effectively futureproof against disruption risk. It also aims to persuade those historically reluctant to prioritise climate change for multiple reasons to consider the implications of uncertainty, when business activity can no longer be guaranteed to remain as usual. When the ecosystem collapses and resources become extinct, supply chains, the financial sector, individuals and communities paralyse and entire nations from the Maldives to Kiribati and Tuvalu disappear; the world will enrich those who are aware and well prepared. Those reliant on the present status quo and a globalised economy without awakening proactively, will experience immeasurable impact costs beyond those projected in this thesis.

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APPENDICES

APPENDIX I: UTAS PHD Participant Informed Survey Consent Form

PHD Topic: THE IMPACT OF CLIMATE CHANGE ON THE FUTURE OF PACIFIC MARITIME SUPPLY CHAINS, SEAPORTS AND SHIPPING: HOW STAKEHOLDERS CAN ADAPT.

This form is to be completed by Pacific maritime supply chain stakeholders who have received a copy of the PHD survey/interview letters inviting participation in this study, a copy of the proposed survey/interview questionnaire, the ethical clearance authorisation form granted by this study along with this UTAS participant consent form.

1. I agree to take part in the research study named above.
2. I have read and understood the participant invitation sheet inviting study participation.
3. The nature and possible effects of the study have been explained to me.
4. I understand that the study involves participation in a survey estimated to take approximately 30-45 minutes in total; that the purpose of the study has been explained and that I will have the opportunity

to review any personal data via an electronic email submission and can withdraw this data at any time

5. I understand that participation may involve potential risks of disclosing commercial information but these risks will be mitigated through the preservation of the conditions of anonymity, de-identifiable data, secure storage and confidentiality proposed.
6. I understand that all research data will be securely stored on the University of Tasmania premises and electronically through an online Cloud for five years from the publication of the study results, and will then be destroyed unless I give permission for my data to be stored in an archive.

   I agree to have my study data archived. Yes ☐ No ☐
7. Any questions that I have asked have been answered to my satisfaction.
8. I understand that the researcher(s) will maintain confidentiality and that any information I supply to the researcher(s) will be used only for the purposes of the research. Any personal information will not be disclosed to other participants. Only a summary of results, thesis and website link to data after personal data is de-identified, will be offered as a possibility for candidates
9. I understand through the invitation to participate that the researcher has indicated how my ethical rights will be safeguarded under specific portions of the Australian Code for the Responsible Conduct of Research and by the Tasmanian Social Sciences Human Research Ethics Committee (HREC).
10. I understand that the results of the study will be published so that I cannot be identified as a participant.
11. I understand that my participation is voluntary and that I may withdraw at any time without any effect.

    If I so wish, I may request that any data I have supplied be withdrawn from the research until [date]. **or** [if it will not be possible to withdraw data] I understand that I will not be able to withdraw my data after completing the survey as it will have been collected anonymously. However, I will be able to remove interview and other personal data at any time provided I give clear informed consent.

Participant's name: ____

Participant's signature: ____

Date: ________________________

Statement by Investigator

☐ I have explained the project and the implications of participation in it to this volunteer and I believe th the consent is informed and that he/she understands the implications of participation.

If the Investigator has not had an opportunity to talk to participants prior to them participating, the following must be ticked. The participant has received the Interview/Survey letter inviting participation where my details have been provided so participants have had the opportunity to contact me prior to consenting to participate in this project.

☐

Investigator's name: ____

Investigator's signature: ____

Date: ____________________

Thank you for the valuable time and attention that you have committed to answering the questions. If there are any additional concerns, if you would like further information, a results summary and/or a copy of this research once completed, please feel free to contact the principal field investigator Jack Dyer at Jack.Dyer@utas.edu.au or +610473985236 or the candidate's supervisors Dr Oanh Nguyen at Oanh.Nguyen@utas.edu.au or Dr Hossein Enshaei at Hoissein.Enshaei@utas.edu.au or the University of Tasmania Ethics Office at Katherine.Shaw@utas.edu.au

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UNIVERSITY of TASMANIA | AMC Australian Maritime College

APPENDIX II: Invitation Letter to participate in a survey about the economic impact of climate change on Pacific maritime supply chains.

Dear Sir/Madam

1. Invitation

Thank you for your valuable time. My name is Jack Dyer and I am a doctoral candidate at the Australia Maritime College, University of Tasmania, Australia. This research is conducted as a partial fulfilment of my PHD Degree in Maritime and Logistics Management under the supervision of Dr Hong-Oanh Nguyen, Professor Young-Tae Chang and Dr Hossein Enshaei.

2. What is the purpose of this study?

The main purpose of this research is to identify the potential risks and economic impact of climate change on Pacific maritime supply chain stakeholders and to evaluate potential adaptation response solutions, including possible constraints to implementing adaptation.

3. Why have I been invited to participate?

As your insights, experience and knowledge are expected to be highly relevant to improve this research, I would kindly request you to participate in a survey/interview that will help me to gain greater awareness of your current status concerning information related to climate change risks. I would like to know how these have previously and potentially may affect your individual supply chain business and throughout the entire maritime supply chain. I would also highly appreciate your views on any potential adaptation solutions, including possible constraints to adapting solutions.

4. What will I be asked to do?

You will be asked to carry out a survey. The survey will take approximately 45-60 minutes of your valuable time. If you are interested, a voluntary follow-up interview lasting between 15-90 minutes can be conducted by indicating this on the attached survey. A copy of the survey/interview questions is attached. All individual responses collected through the interview, including the results and contact information of participant company, authority and individual stakeholders will be treated as strictly confidential.

5. Are there any possible benefits for participating in this study?

Your participation would be highly appreciated for this research as it represents the first study on the potential impact of climate change on Pacific maritime supply chain stakeholders. While there may be few direct or immediate benefits to you and your organisation/company for taking part, but it is hoped that research investigating the potential disruption risks, impact costs and potential adaptation solutions of climate change, will provide certain indirect or long-term benefits towards aiding Pacific maritime supply chain stakeholders such as you, in preparing to survive with minimal disruption costs.

6. Are there any possible risks from participation in this study?

The survey is not expected to pose any risk or threat to you. Questions are all based on your general knowledge and own experience.

For your reassurance, this survey has been granted research ethics approval by the Tasmanian Social Sciences Human Research Ethics Committee (HREC); the ethics reference number is…This committee and researcher consider this essential to preserve your rights under the 2007 Australian Code For The Responsible Conduct of Research, sections 1.6-1.8 (detailing researcher responsibilities towards research and participants and section 2 (detailing the requirement for researcher responsibilities towards safeguarding research data and primary materials), the similar researcher responsibilities outlined in section 1 of the updated May 2015 version of the 2007 Australia National Statement on Ethical Conduct in Human Research, along with the ethical responsibilities of researchers under the University of Tasmania Research Ethics Policy section 3. These codes are viewable online on the University of Tasmania website and a full copy can be emailed to you by this researcher if required.

7. What if I change my mind during or after the study?

While your participation will be highly appreciated, we will respect your decision to decline or withdraw at any stage. Your participation is entirely voluntary and you are free to withdraw it at any time without providing an explanation. If you agree to participate you will have the right to request the relevant results chapter to ensure that your rights are safeguarded in regards to confidentiality and anonymity. If you choose to withdraw from this survey, I will ask your permission to retain any information that you have been completed so far. You are free to decline this request. Survey data cannot be redacted after 3 months of submission as data will be anonymous and hence the data that have already been processed will not be able to withdrawn. You will also have the right to ask that any data you have provided is removed from the study.

8. What will happen to the information when this study is over?
All the data will be anonymous. In accordance with the research requirement the data will be kept for 5 years from the date of completion of the study.

If you are interested I would be willing to email you a copy of this research thesis, a summary of the results or access to the data via a specific website link after it has formally been examined, accepted and published, in thanks for your generous attention to this email.

If you agree to participate, please sign and returned the attached Consent Form by 30 September 2017 to the investigator below:

9. How will the results of the study be published?

. The study forms part of a PHD thesis Research findings may be presented and published in journals/conferences but only aggregated, results without personal identifying information

10: What if I have questions about the study?

If you have any questions about the study you can contact the field investigator below; the supervisors at Oanh.Nguyen@utas.edu.au, Hossein.Enshaei@utas.edu.au or the University of Tasmania Ethics Office via Katherine.Shaw@utas.edu.au

With the greatest of respect and thanks

Jack Dyer

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Maritime Way
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Launceston, Tasmania 7250, Australia
Email: Jack.Dyer@utas.edu.au
Telephone Number (+61) 04

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APPENDIX III: UTAS PHD Participant Informed Interview Consent Form

PHD Topic: THE IMPACT OF CLIMATE CHANGE ON THE FUTURE OF PACIFIC MARITIME SUPPLY CHAINS, SEAPORTS AND SHIPPING: HOW STAKEHOLDERS CAN ADAPT.

This form is to be completed by Pacific maritime supply chain stakeholders who have received a copy of the PHD survey/interview letters inviting participation in this study, a copy of the proposed survey/interview questionnaire, the ethical clearance authorisation form granted by this study along with this UTAS participant consent form.

1. I agree to take part in the research study named above.
2. I have read and understood the participant invitation sheet inviting study participation.
3. The nature and possible effects of the study have been explained to me.
4. I understand that the study involves participation in an interview estimated to take approximately 15-90 minutes in total; that the purpose of the study has been explained and that I will have the opportunity to review any personal data via an electronic email submission and can withdraw this data at any time
5. I understand that participation may involve potential risks of disclosing commercial information but these risks will be mitigated through the preservation of the conditions of anonymity, de-identifiable data, secure storage and confidentiality proposed.
6. I understand that all research data will be securely stored on the University of Tasmania premises and electronically through an online Cloud for five years from the publication of the study results, and will then be destroyed unless I give permission for my data to be stored in an archive.
   I agree to have my study data archived. Yes ☐ No ☐
7. Any questions that I have asked have been answered to my satisfaction.
8. I understand that the researcher(s) will maintain confidentiality and that any information I supply to the researcher(s) will be used only for the purposes of the research. Any personal information will not be disclosed to other participants. Only a summary of results, thesis and website link to data after personal data is de-identified, will be offered as a possibility for candidates

9. I understand through the invitation to participate that the researcher has indicated how my ethical rights will be safeguarded under specific portions of the Australian Code for the Responsible Conduct of Research and by the Tasmanian Social Sciences Human Research Ethics Committee (HREC).
10. I understand that the results of the study will be published so that I cannot be identified as a participant.
11. I understand that my participation is voluntary and that I may withdraw at any time without any effect.

    If I so wish, I may request that any data I have supplied be withdrawn from the research until [date]. **<u>or</u>** [if it will not be possible to withdraw data] I understand that I will not be able to withdraw my data after completing the survey as it will have been collected anonymously. However, I will be able to remove interview and other personal data at any time provided I give clear informed consent.

Participant's name: ____

Participant's signature: ____

Date: ____________________

Statement by Investigator

☐ I have explained the project and the implications of participation in it to this volunteer and I believe th the consent is informed and that he/she understands the implications of participation.

If the Investigator has not had an opportunity to talk to participants prior to them participating, the following must be ticked. The participant has received the Interview/Survey letter inviting participation where my details have been provided so participants have had the opportunity to contact me prior to consenting to participate in this project.

☐

Investigator's name: ____

Investigator's signature: ____

Date: ____________________

Thank you for the valuable time and attention that you have committed to answering the questions. If there are any additional concerns, if you would like further information and/or a summary of the results once completed and supervisor approved prior to submission as a thesis, please feel free to contact the principal field investigator Jack Dyer at Jack.Dyer@utas.edu.au or (+61)0473985236; the candidate's supervisors Dr Oanh Nguyen at Oanh.Nguyen@utas.edu.au or Dr Hossein Enshaei at Hossein.Enshaei@utas.edu.au or the University of Tasmania Ethics Office at Katherine.Shaw@utas.edu.au

Jack Dyer,
Locked Bag 1397,
National Centre for Ports and Shipping,
Maritime Way,
University of Tasmania,
Launceston, Tasmania Australia.
7250

APPENDIX IV: Invitation Letter to participate in an interview about the economic impact of climate change on Pacific maritime supply chains.

Dear Sir/Madam

1. Invitation

Thank you for your valuable time. My name is Jack Dyer and I am a doctoral candidate at the Australia Maritime College, University of Tasmania, Australia. This research is conducted as a partial fulfilment of my PHD Degree in Maritime and Logistics Management under the supervision of Dr Hong-Oanh Nguyen, Professor Young-Tae Chang and Dr Hossein Enshaei.

2. What is the purpose of this study?

The main purpose of this research is to identify the potential risks and economic impact of climate change on Pacific maritime supply chain stakeholders and to evaluate potential adaptation response solutions, including possible constraints to implementing adaptation.

3. Why have I been invited to participate?

As your insights, experience and knowledge are expected to be highly relevant to improve this research, I would kindly request you to participate in a survey/interview that will help me to gain greater awareness of your current status concerning information related to climate change risks. I would like to know how these have previously and potentially may affect your individual supply chain business and throughout the entire maritime supply chain. I would also highly appreciate your views on any potential adaptation solutions, including possible constraints to adapting solutions.

4. What will I be asked to do?

Having been asked to undertake a survey, you will be asked to undertake a follow up interview lasting between 15-90 minutes can be conducted by indicating this on the attached informed consent form. A copy of the survey/interview questions is attached. All individual responses collected through the interview, including the results and contact information of participant company, authority and individual stakeholders will be treated as strictly confidential.

5. Are there any possible benefits for participating in this study?

Your participation would be highly appreciated for this research as it represents the first study on the potential impact of climate change on Pacific maritime supply chain stakeholders. While there may be few direct or immediate benefits to you and your organisation/company for taking part, but it is hoped that research investigating the potential disruption risks, impact costs and potential adaptation solutions of climate change, will provide certain indirect or long-term benefits towards aiding Pacific maritime supply chain stakeholders such as you, in preparing to survive with minimal disruption costs.

6. Are there any possible risks from participation in this study?

The survey is not expected to pose any risk or threat to you. Questions are all based on your general knowledge and own experience.

For your reassurance, this survey has been granted research ethics approval by the Tasmanian Social Sciences Human Research Ethics Committee (HREC); the ethics reference number is…This committee and researcher consider this essential to preserve your rights under the 2007 Australian Code For The Responsible Conduct of Research, sections 1.6-1.8 (detailing researcher responsibilities towards research and participants and section 2 (detailing the requirement for researcher responsibilities towards safeguarding research data and primary materials), the similar researcher responsibilities outlined in section 1 of the updated May 2015 version of the 2007 Australia National Statement on Ethical Conduct in Human Research, along with the ethical responsibilities of researchers under the University of Tasmania Research Ethics Policy section 3. These codes are viewable online on the University of Tasmania website and a full copy can be emailed to you by this researcher if required.

7. What if I change my mind during or after the study?

While your participation will be highly appreciated, we will respect your decision to decline or withdraw at any stage. Your participation is entirely voluntary and you are free to withdraw it at any time without providing an explanation. If you agree to participate you will have the right to request the relevant personal data and results summary to ensure that your rights are safeguarded in regards to accuracy, confidentiality and anonymity. If you choose to withdraw from this survey, I will ask your permission to retain any information that you have been completed so far. You are free to decline this request. Survey data cannot be redacted after 3 months of submission as data will be anonymous and hence the data that have already been processed will not be able to withdrawn. Interview data being personal can be withdrawn. You will also have the right to ask that any data you have provided is removed from the study.

8. What will happen to the information when this study is over?

All the data will be anonymous. In accordance with the research requirement the data will be kept for 5 years from the date of completion of the study.

If you are interested I would be willing to email you a copy of this research thesis, a summary of the results or access to the data via a specific website link after it has formally been examined, accepted and published, in thanks for your generous attention to this email.

If you agree to participate, please sign and returned the attached Consent Form by 30 September 2017 to the investigator below:

9. How will the results of the study be published?

The study forms part of a PHD thesis Research findings may be presented and published in journals/conferences but only aggregated, results without personal identifying information

10: What if I have questions about the study?

If you have any questions about the study you can contact the field investigator below; the supervisors at Oanh.Nguyen@utas.edu.au, Hossein.Enshaei@utas.edu.au or the University of Tasmania Ethics Office via Katherine.Shaw@utas.edu.au

With the greatest of respect and thanks

Jack Dyer

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Appendix V: Survey/Interview Questions

Study Title: The Impact of Climate Change On The Future Of Pacific Maritime Supply Chains, Seaports and Shipping: How Stakeholders Can Adapt

Respondent Code: ______________________________

Date of Submission: ______________________________

For each of the following questions, please tick in the appropriate column and provide feedback in the space provided.

SECTION A: SURVEY QUESTIONS

1a: How aware are you and your company/organisation/association about the potential risks of climate change? Please feel free to provide examples.

1aii: How aware are you and your company/organisation/association about the potential impact costs, of climate change?

1aiii: How aware are you and your company/organisation/association about the potential adaptation response solutions of climate change by international professional associations; research and competitors?

1bi: How aware is your business of national and international climate change legislation and disaster risk management policy strategies.

1bii: How aware is your business of potential adaptation funding sources?

2a: Are any of the climate change risk events of the past, present or future in 2b below of concern your business operations/company/association individually and across the Pacific maritime supply chain

No Yes Information is not available

2b: If so, which specific long-term climate change disruption risks are of most concern to your business operations or organisation individually and across the Pacific maritime supply chain?

(Please rank in order of importance from 1-5 with 1 being the least significant and 5 being the most significant)

- 2.1: Sea Level Rise ☐
- 2.2: Precipitation ☐
- 2.3: Temperature/Humidity Increases ☐
- 2.4: Wind velocity ☐
- 2.5: Changes in currents ☐
- 2.6: Changes in wave energy ☐
- 2.7: Changes in soil sedimentation and composition ☐
- 2.8: Changes in Species Migration and Biodiversity ☐
- 2.9: Changes in ocean acidification/increases in salinity/coral bleaching ☐
- 2:10: Other (Please specify) ☐

2c: Please indicate why and how, the above risk events are of most concern to you/your business, or organisation?

3a: Are any of the below climate change-related disruption risk events of the past, present or future; of concern to your business operations/organisation individually and across the Pacific maritime supply chain

No ☐ Yes ☐ Information Not Available ☐

3b: If so, which specific short-term climate change disruption risks are of most concern to your business operations/company/association individually and across the Pacific maritime supply chain?

(Please rank in order of importance from 1-5 with 1 being the least significant and 5 being the most significant)

- 3.1: Storms/Superstorms/Storm surges ☐
- 3.2: Floods ☐
- 3.3: Cyclones ☐
- 3.4: Tsunamis
- 3.5: Droughts ☐

- 3.6: Heatwaves ☐
- 3.7: Landslides ☐
- 3.8: Earthquakes ☐
- 3.9: Other (Please specify) ______________________________ ☐

3c: Please indicate why and how, the above risk events are of concern to you/your business, company or organisation?

4a: Have any of the above risk events, previously disrupted your/your business's operations over the last 100 years?

No ☐ Yes ☐

4b: If yes, please provide the risk type, date and duration in days, months and years for each risk event, separately where possible.

4c: Which assets/resources/systems/infrastructure/resources/products/equipment were affected specifically for each risk event?

4d: How often did each asset fail from these risks?

4e. How long did each asset take to recover performance in days?

Please describe the risk event, asset, and information on factors which influence vulnerability for a supply chain asset (labour, capital, technology, communication/information, equipment and infrastructure) including its projected design, material, life expectancy, asset condition including frequency of maintenance, age, experience, resources, education and training or by past exposure to risk and the extent to which effective repairs/maintenance are conducted and degree of climate proofing. Please also include where possible, technical standards to preserve asset condition and functionality or service life and asset resilience or shock absorption capacity. This information will assist in calculating past/anticipated conditional probability of a maritime supply chain specific asset/resource/system failure from a climate change risk event

4f: Which assets/resources/systems /infrastructure/equipment/resources/products/equipment are likely to fail and how often, given a future specific risk?

Please also include information either below or attached, (which you possess). These factors include the extent and condition of natural resources needed for your business/organisation as inventory if known, in all production and processing stages; extent of local land, ocean and atmosphere carbon/pollutant sinks and ecosystem plus natural coastal protection defences including seagrasses, mangroves and other coastal ecosystems.

5a: If affected by a risk above, for each risk event, (separately where possible); what were the projected impact cost types and size estimates in $ for each asset lost, damaged, delayed or replaced? Please tick and provide information only on whichever impact costs are available and relevant –the costs below refer to the entire maritime supply chain and may not all apply to each participant

Potential Impact cost types include: **Cost Experienced** **Value:**

- Physical commodity damage ☐
- Physical asset/infrastructure clean-up ☐
- damage costs, ☐
- repair costs, ☐
- asset replacement costs, ☐
- recovery costs, ☐
- Cost examples include port approaches, port limits, breakwaters, turning basins, berths, docks, channels, pavements, container stacking areas, quay walls, port authority, customs and other buildings, damage to terminals, cargo warehouses, offices, hazardous cargo storage zones, businesses, offices, water, electricity, sewerage and bunkerage.

- Port and supply chain service costs including pilotage, mooring, tugs and towing, salvaging, dredging, customs, stevedoring, drydocks/repairs, waste disposal, navigation, vessel tracking, security, hazard warning systems, inspection, freight forwarding ☐

- Equipment damage, repair and maintenance costs. ☐

Examples include operator vehicles, synchrolifts, stacking equipment, cranes, container scanning facilities, reach stackers and container reefer points.

Cost Type: **Cost Experienced** **Value**

- Costs to Production/Productivity: To processes, material inputs, outputs and equipment ☐
- Increased evacuation/relocation costs ☐
- Production/disruption/sales revenue/input costs ☐
- Increased employment, wage, health and safety and other labour costs ☐
- Increased ecosystem, environmental damage/coastal erosion/ costs ☐
- Psychological; Health and Safety ☐
- Port Throughput value ☐
- Damage to technology –security, navigation, customs, administration. ☐
- Increased cleaning/storage costs ☐
- Increased cargo loading/unloading costs and other port/cargo dues ☐
- Physical equipment/technology and systems damage ☐
- Loss of Life ☐
- Economic/Commercial -supply, demand, market type ☐
- Loss of customs/tax revenue ☐
- Export revenue cost/Increased import/transhipment cost ☐
- Trade diversion and contingency rerouting costs ☐
- Training ☐
- Information/Research ☐
- Communication ☐
- Financial including profits, capital potential, bankruptcy, insolvency and insurance ☐
- Increased legal, technical and regulatory compliance costs ☐
- Marketing/Administrative ☐

- Reputational ☐
- Congestion ☐
- Opportunity (To other potential uses of resources/time etc) ☐
- Navigational/Port safety ☐

➢ Shipping costs: ☐

➢ Time, voyage and spot charter costs, brokerage costs, contract of carriage penalty charges. ☐

➢ Road/Rail Transport and logistics ☐

➢ Consumption/consumer costs ☐

- Subsequent climate change mitigation, adaptation, asset recovery, retreat/surrender, migration and ecological rehabilitation response strategy costs ☐
- Other (Please specify) ____ ☐

5b: For how long did these risk events affect operations? /How did these risks affect operations?

6a: Have you or your company/organisation/association adapted to climate change, either from a specific event or from anticipated risks?

No ☐ Yes ☐

6bi: If so, which of the following is your business/organisation currently doing or considering doing, to plan and to adapt to potential change?

- Natural Engineering/Ecological Rehabilitation ☐
- Increasing environmental sustainability/reducing emissions (Mitigation) ☐
- Physical Engineering –Climateproofing ☐
- Investing in new equipment/technology and other assets ☐
- Facility Elevation ☐
- Retreat-Surrender ☐
- Information ☐
- Training ☐
- Communication ☐
- Market/Input/Income Source Diversification ☐

- Intermodalism ☐
- Increasing Flexibility ☐
- Legislation and reviewed policy planning ☐
- Taxes, subsidies, fines or other financial incentives ☐
- Infrastructure Technical Standards ☐
- Risk monitoring/management ☐
- Increased Cooperation across Maritime Supply Chain Stakeholders ☐
- Increased Information Sharing across Maritime Supply Chain Stakeholders ☐
- Other (Please specify) ____________________ ☐

6bii: If so, what is your business/organisation currently doing or considering doing, to plan and to adapt to potential change? Please detail any potential practises, policies and measures with specific examples of the solutions.

6c: For the adaptation strategies indicated above in 6bi, please indicate why you/your company/organisation would prioritise these solutions over others. Please provide any estimated adaptation costs or resources necessary to successfully adapt if possible

6d: Which long and short-term climate change risks from the list below/in questions 2/3, are you/is your organisation most prepared for and how?

- 2.1: Sea Level Rise ☐
- 2.2: Precipitation ☐
- 2.3: Temperature/Humidity Increases ☐
- 2.4: Wind velocity ☐
- 2.5: Changes in currents ☐
- 2.6: Changes in wave energy ☐
- 2.7: Changes in soil sedimentation and composition ☐
- 2.8: Changes in Species Migration and Biodiversity ☐
- 2.9: Changes in ocean acidification/increases in salinity/coral bleaching ☐
- 2:10: Other (Please specify) ☐
- 3.1: Storms/Superstorms/Storm surges ☐

- 3.2: Floods ☐
- 3.3: Cyclones ☐
- 3.4: Tsunamis ☐
- 3.5: Droughts ☐
- 3.6: Heatwaves ☐
- 3.7: Landslides ☐
- 3.8: Earthquakes ☐
- 3.9: Other (Please specify) ☐

6e: Which long and short-term climate change risks from the list above/questions 2/3, are you/is your company least prepared for?

7a: Have any significant constraints to climate change adaptation been noticed from risk events?

No ☐ Yes ☐ If no please go to Question 8

7b: If yes, what constraints to climate change adaptation are noted by you/your company/organisation/association of the following? (Please rank in order of importance from 1-8 with 1 being the least significant and 8 being the most significant). Please feel free to include less than 8, still ranked in order of importance.

	Constraint	Order of Significance
• Land/Geophysical (environmental, relocation and opportunity costs for existing facilities from tides, rivers, currents and the ocean)	☐	☐
• Information	☐	☐
• Communication	☐	☐
• Labour	☐	☐
• Capital	☐	☐
• Financial/Funding	☐	☐
• Commercial: Profits	☐	☐
• Fixed costs	☐	☐
	☐	

- Variable costs ☐
- Legal ☐ ☐
- Social ☐ ☐
- Environmental ☐ ☐
- Political ☐ ☐
- Administrative ☐ ☐
- Technical/Technological ☐ ☐
- Coordination ☐ ☐
- Cooperation from other stakeholders ☐ ☐
- Education/Training ☐ ☐
- Planning/zoning ☐ ☐
- Transport ☐ ☐
- Uncertainty of climate change projections ☐ ☐
- Other (Please specify) ____________________ ☐

7ci: How effective are existing and proposed adaptation solutions recommended by researchers, governments, nongovernmental organisations and others?

7cii: Have any other constraints/issues been identified?

8: Have you, your company/organisation interacted or considered interacting with other supply chain stakeholders to coordinate a projected response to climate change to minimise disruption costs to you, your customers/ other stakeholders? No ☐ Yes ☐

8aii: If yes, how have your company/organisation specifically cooperated with other stakeholders

8b: If not, why not?

SECTION B: STAKEHOLDER PROFILE:

I: Please identify which of the following Pacific maritime supply chain stakeholders you individually/your business, company, organisation or association most accurately represent for this survey:

- Individual subsistence fishing business ☐
- Commercial Producer/user of maritime related resources/products: ☐
- Company/corporation with international operations ☐
- Maritime industry/value adding/beneficiation/processing ☐
- Maritime administration ☐
- Maritime agency ☐
- Seaport/Terminal ☐
- Customs/Tax office ☐
- Government ministry ☐
- Shipping operator/owner/agent/company ☐
- Import/export, freight forwarding and transhipment ☐
- Road/rail/air transport and logistics ☐
- Wholesale, storage and distributors or distribution centres ☐
- Marketing/Publicity ☐
- Retail including shops, restaurants and other businesses ☐
- Consumer ☐
- Financial/insurance service sector ☐
- Professional association (Please specify type) ____________________ ☐
- Academia/research ☐
- Non-governmental organisation ☐
- Community/religious/cultural association member/leader ☐
- Other (Please specify) ____________________ ☐

II: Please indicate the number of years you have been involved in the above:

Less than 5 years ☐ 5-10 years ☐ 11-20 years ☐ More than 20 years ☐

III: Please indicate the number of years your company/organisation/association/business has been established.

Less than 5 years ☐ 5-10 years ☐ 11-20 years ☐ 20 -30 years ☐ Over 30 ☐

IV: Please indicate your highest level of educational qualification

Secondary ☐ Diploma ☐ Tertiary Degree ☐ Postgraduate ☐ Professional ☐

Prefer Not to Say ☐

V: What are the main priorities/objectives for your company/organisation/association?

Please feel free to provide more specific details related to your business/organisation/association

Are you available for a follow up interview to discuss any particular questions or concerns?

N ☐ ☐

If so, please arrange contact through the following details.

Thank you for the valuable time and attention that you have committed to answering the questions. If there are any additional concerns, if you would like further information and/or a copy of this research once completed submission as a thesis, please feel free to contact the principal field investigator Jack Dyer at Jack.Dyer@utas.edu.au or (+61) 04 or

Jack Dyer,
Locked Bag 1397,
National Centre for Ports and Shipping, Maritime Way,
University of Tasmania,
Launceston, Tasmania, Australia.
7250

APPENDIX VI: UTAS PHD Reminder Email:

Topic: Participation in the survey/interviews relating to THE IMPACT OF CLIMATE CHANGE ON THE FUTURE OF PACIFIC MARITIME SUPPLY CHAINS, SEAPORTS AND SHIPPING: HOW STAKEHOLDERS CAN ADAPT.

Dear Sir/Madam

Once more I sincerely apologise for the intrusion upon your valuable time. As you will be aware from my previous email dated…), I am conducting the first PHD research study on the potential risks and economic impact costs of climate change for Pacific maritime supply chain stakeholders and to evaluate potential adaptation response strategy solutions, including possible constraints to implementing adaptation. In my previous email (repeated below), we invited you to participate in a survey and express interest in a following interview. If you have completed the survey, I thank you for your valuable time and insight. If you have not, we invite you to complete the survey again through the link… or through the attached pdf questionnaire form and emailed directly to the email address Jack.Dyer@utas.edu.au provided below by 31 October 2017. Climate change is projected to have many uncertain risks and impact costs, especially for Pacific maritime supply chains and this research's purpose aims to enhance stakeholder's resilience through awareness and adaptation. We would highly appreciate any assistance that you might be able to provide to enhance the quality and relevance of this research. As indicated earlier, if you are interested I would be willing to email you a copy of this research thesis after it has formally been examined, accepted and published, in thanks for your generous attention to this email.

With the greatest of respect and thanks

Yours sincerely

Jack Dyer
Locked Bag 1397
Launceston, Tasmania 7250, Australia
Email: Jack.Dyer@utas.edu.au
Telephone Number (+61) 04

Appendix VII: University of Tasmania Ethics Application Approval

Social Science Ethics Officer
Private Bag 01 Hobart
Tasmania 7001 Australia
Tel: (03) 6226 2763
Fax: (03) 6226 7148
Katherine.Shaw@utas.edu.au

HUMAN RESEARCH ETHICS COMMITTEE (TASMANIA) NETWORK

28 August 2017

Dr Hong-Oanh Nguyen
Maritime and Logistics Management
Australian Maritime College
University of Tasmania

Student Researcher: Jack Dyer

Sent via email

Dear Dr Nguyen

Re: FULL ETHICS APPLICATION APPROVAL
Ethics Ref: **H0016602 - The Impact of Climate Change on the Future of Pacific Maritime Supply Chains, Seaports and Shipping: How Stakeholders Can Adapt**

We are pleased to advise that the Tasmania Social Sciences Human Research Ethics Committee approved the above project on 28 August 2017.

This approval constitutes ethical clearance by the Tasmania Social Sciences Human Research Ethics Committee. The decision and authority to commence the associated research may be dependent on factors beyond the remit of the ethics review process. For example, your research may need ethics clearance from other organisations or review by your research governance coordinator or Head of Department. It is your responsibility to find out if the approval of other bodies or authorities is required. It is recommended that the proposed research should not commence until you have satisfied these requirements.

Please note that this approval is for four years and is conditional upon receipt of an annual Progress Report. Ethics approval for this project will lapse if a Progress Report is not submitted.

The following conditions apply to this approval. Failure to abide by these conditions may result in suspension or discontinuation of approval.

1. It is the responsibility of the Chief Investigator to ensure that all investigators are aware of the terms of approval, to ensure the project is conducted as approved by the Ethics Committee, and to notify the Committee if any investigators are added to, or cease involvement with, the project.

2. Complaints: If any complaints are received or ethical issues arise during the course of the project, investigators should advise the Executive Officer of the Ethics Committee on 03 6226 7479 or human.ethics@utas.edu.au.

3. Incidents or adverse effects: Investigators should notify the Ethics Committee immediately of any serious or unexpected adverse effects on participants or unforeseen events affecting the ethical acceptability of the project.

4. Amendments to Project: Modifications to the project must not proceed until approval is obtained from the Ethics Committee. Please submit an Amendment Form (available on our website) to notify the Ethics Committee of the proposed modifications.

5. Annual Report: Continued approval for this project is dependent on the submission of a Progress Report by the anniversary date of your approval. You will be sent a courtesy reminder closer to this date. **Failure to submit a Progress Report will mean that ethics approval for this project will lapse.**

6. Final Report: A Final Report and a copy of any published material arising from the project, either in full or abstract, must be provided at the end of the project.

Yours sincerely

Katherine Shaw
Executive Officer
Tasmania Social Sciences HREC

Appendix VIII: Cook Islands Research Ethics Application Approval

COOK ISLAND RESEARCH COMMITTEE
OFFICE OF THE PRIME MINISTER
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16th October 2017

Mr Jack Dyer
University of Tasmania
Tasmania
Australia

Kia Orana,

RE: APPROVED RESEARCH APPLICATION

I am pleased to advise that the National Research Committee has granted approval for your research titled **"The Impact of Climate Change on the Future of Pacific Maritime Supply Chains, Seaports And Shipping: How Stakeholders Can Adapt"** in **Rarotonga** from **16th October 2017** to **16th October 2018**

Enclosed is your research permit issue **# 27/17**

The following conditions listed below have been imposed by the National Research Committee

- **The researcher complies with the Cook Islands Immigration**
- **The researcher provides a preliminary report to the Office of the Prime Minister at the earliest**
- **The researcher provides three (3) hard copies + one (1) e-copy of the final output generated from**
- **The researcher provides a preliminary report to the Office of the Prime Minister at the earliest**
- **The researcher provides three (3) hard copies + one (1) e-copy of the final output generated from**
this research to the Office of the Prime Minister by June 2019.

Kia Manuia

Bredina Drollet
CHAIRPERSON

Appendix IX: Historical Climate Change Risks For Pacific Maritime Supply Chains

Cook Islands (Chapter 5)

Historical Pacific Climate Change Risk Chronology Cook Islands			
Year	No of Risk Events	Date (Where Information Available)	C/S Average Risk Event Duration (No of Days)
1900			0
1901			0
1902			0
1903			0
1904	C	1/01/1904	1
1905	S, C	03/2006	1
1906			0
1907			0
1908			0
1909		7/02/1909	0
1910			0
1911			0
1912	C	03/2012	1
1913			0
1914	S, C, T	05/2014	1
1915			0
1916			0
1917			0
1918			0
1919	E	6/06/1919	0
1920			0
1921			0
1922			0
1923			0
1924			0
1925			0
1926	S, C	T -31/03/1926; S/C -16-23/11	7
1927			0
1928			0
1929	C		1
1930			0
1931	S, C, S+C	4/02/1931	1
1932			0
1933			0
1934			0
1935	S, C	10/03/1935	1
1936			0
1937			0
1938			0
1939	D	05...08/1939	0
1940			0
1941	S, C, S+C,	13-19/01/1941; 19-26/02/1941	6
1942	S, C, S+C	13/02/1942	6
1943	2S, 2C, 2 (S+C)	06/03/1943	1
1944	S, C, (S+C)	31/01/1944	1
1945			0
1946	S, C, (S+C)	13/14/01/1946	2
1947			0

1948	C	13-14/07/1948	1
1949			0
1950*	2C	01.1950	5
1951			0
1952			0
1953	H, S, T	07…09/1953	0
1954			0
1955	H	07…09…1955	0
1956			0
1957			0
1958			0
1959	S, C, S+C	11-16/02/1959	3
1960	H, T	T- 22/05/1960, H- 06…09/1960	2
1961			0
1962			0
1963	2S, 2 C, 2 (S+C)	07/03/1963, 12-14/2003	2
1964	H	6/09/1964	0
1965			0
1966			0
1967	2S, C	16/12/1967	1
1968			0
1969	2C, H	11-25/03, 27/02-6/03/1969	12
1970			0
1971	H, G	17-19/12/1971	0
1972	C	22-28/03/1972	6
1973	H		0
1974	H		0
1975	H		0
1976			0
1977			0
1978			0
1979			0
1980	2S, 1 G	G-23-28/02/1980	0
1981	S	17-24/03/1981	7
1982	G	25/02-06/03/1982	0
1983			0
1984			0
1985			0
1986			0
1987	S, C, S+C	28/12-05/01/1987	8
1988	H		0
1989	C	22-28/02/1989	6
1990	S, C, S+C	13-18/02/1990, 30/11-04/12/1990, 06-13/12/1990,	7
1991	S	15-19/03/1991	5
1992	S	12-16/02/1992	4
1993			1
1994	S	14/02/1994	1
1995			0
1996	H, C, S, (S+C)	07-17/01/1996	10
1997	2H, 2C, S, G, S+C	S- 06-10/12/1997, C- 07/11/1997, C-24-28/12/1997, G-21-25/04/1997	5
1998			0

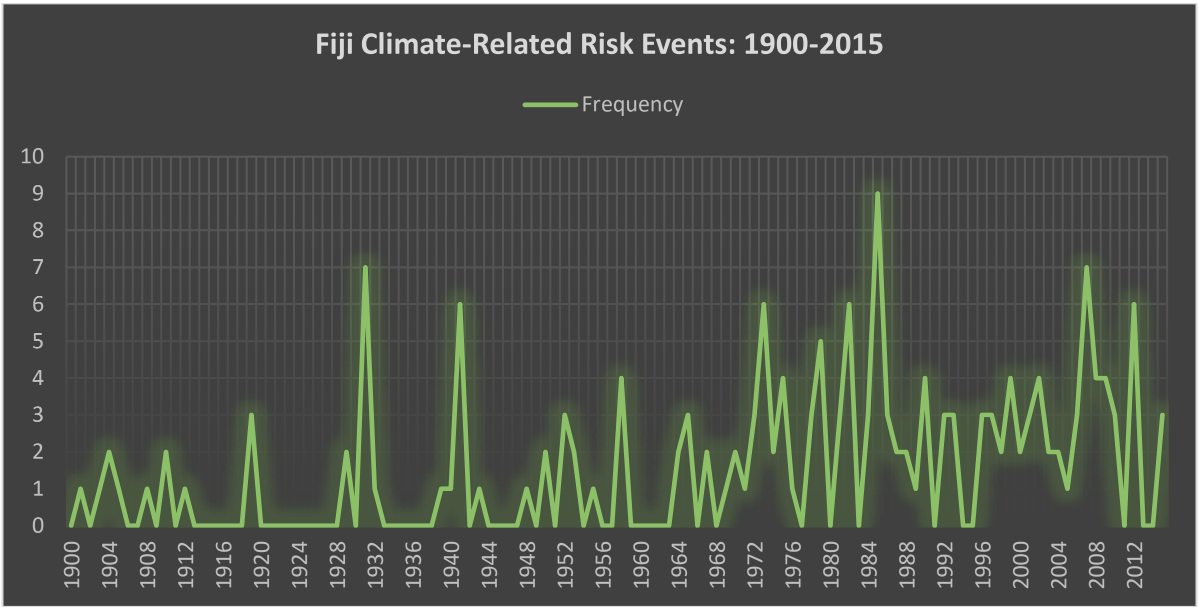
1999	H		0
2000	H		0
2001	S, C, F	F-5/12/2001, C-03/12/2001, S-29/11-03/12/2001	1
2002	C	06-11/02/2002	5
2003			0
2004			0
2005	3C	3-8/02/2005, 10-17/02/2005, 28/02-05/2005	6
2006			0
2007	H		1
2008	H		1
2009			0
2010	T, E, C, S	T/E-13/04/2010, S-11/02/2010, C06/02-10/02/2010	4
2011			0
2012			0
2013			0
2014			0
2015	D	25/02-31/12/2015	0

FIJI

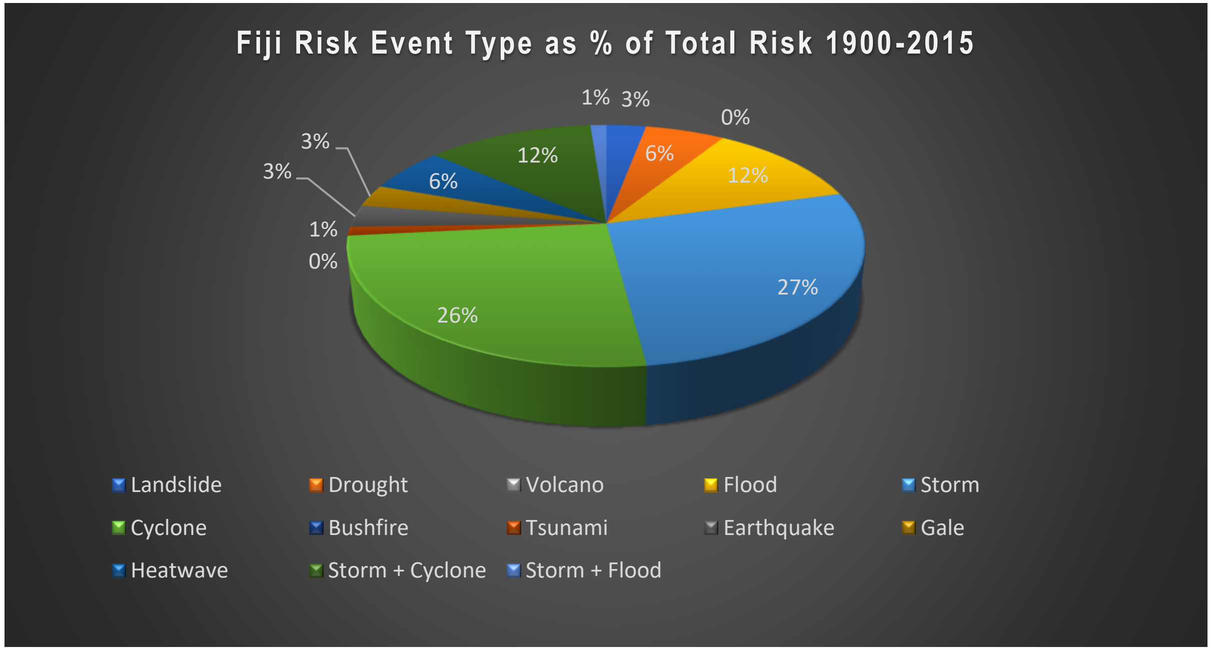
Historical Pacific Climate Change Risk Chronology Fiji		
Year	**No of Risk Events**	**Date (Where Information Available)**
1900		
1901	S	
1902		
1903	C	
1904	S, C	
1905	C	
1906		
1907		
1908	C	March
1909		
1910	C, S	March
1911		
1912	S	January
1913		
1914		
1915		
1916		
1917		
1918		
1919	E, 2S	E-03/10/1919, S-03/1919
1920		
1921		
1922		
1923		
1924		
1925		
1926		
1927		

1928		
1929	C, S	December
1930		
1931	2S, 2C, S+C, 2E	16/02-03S/C,
1932	E	08/03
1933		
1934		
1935		
1936		
1937		
1938		
1939	C	January
1940	D	
1941	D, 2S, 2C, S+C	S/C -19/02
1942		
1943	S	
1944		
1945		
1946		
1947		
1948	C	
1949		
1950	2S	
1951		
1952	S, C, S+C	28/01/1952,
1953	E, T	
1954		
1955	S	
1956		
1957		
1958	2S, C, S+C	C-07/01/1958
1959		
1960		
1961		
1962		
1963		
1964	F, C	C-22/03,
1965	S, C, F	F -07/02
1966		
1967	D, S	
1968		
1969	D	
1970	H, G	G-16-19/12/1970
1971	H	
1972	C, S, S+C,	C-19-28/10/1972, 19-22 Jan
1973	D, H, S, C S+C, G	G-28/02-02/03/1973,
1974	2S	24-28/01/1974
1975	S, 2C, H	29/01-05/02/1975, 30/04-05/1975
1976	S	
1977		
1978	S, C, S+C,	S-04/02/1978, C-27/02/1978
1979	S, C, S+C, G, E,	G-02-07/04/1979, S-22-27/03/1979, C 24/03/1979, E-16/11/1979

1980		
1981	S, C, D	24/01-06/02/1981
1982	2C, F, S+F, S, D	23-02-06/03/1982, 23/03-03/04/1982
1983		
1984	F, C, H	25/03/1984
1985	3S, 3C, 3(S+C)	12-20/01/1985, 8-12/02/1985, 10-14/0/1985
1986	S, C, F	21/12-05/01
1987	S, H	8/01/1987
1988	S, H	24/02-04/03/1988
1989	F	
1990	H, S, 2C	24-30/11/1990; 26-31/12/1990
1991		
1992	S, C, S+C	01-05/01/1992; 03-13/12/1992
1993	S, C, S+C	5-9/02/1993; 15-18/02/1993
1994		
1995		
1996	2S, 1C	20/01-01/02/1996; 02-12/03/1996; 3-5/05/1996;
1997	S, C, S+C	12-21/03/1997; 06-12/10/1997;
1998	C, D	21/01/1998;
1999	S, C, S+C, G	19/01/1999; 12/02/1999; 19-22/09/1999; 22-23/09/1999
2000	C, F	17-24/01/2000; 16/12/2000;
2001	S, C, S+C	20/02-04/03/2001;
2002	S, C, F, S+C	12-15/01/2002;
2003	S+F, C	
2004	L, F	05/06/2000-F
2005	F	28/09/2005-F
2006	L, 2F	04/02/2006-F;
2007	3F, 2L, 2(C+S)	03/02/2007-F; 0903/2007-F
2008	S, C, S+C, F	28/01/2008-F; 25/01-09/02/2008
2009	C, F, C+F, T	14/12/2009-F; 14/03/2009; 03-15/12/2009; 08/01/2009-T
2010	C, F, C+F	14/03/2010-F; 09-17/03/2010
2011		
2012	2F, L, F+L, S, C, S+C	22/01/2012-L; 28/03/2012; 9-19/12/2012;
2013		
2014		
2015	D, C, S	04/03,
2016	C	



Fiji Climate-Related Risk Events: 1900-2015
Frequency
10
9
8
7
6
5
4
3
2
1
0
1900
1904
1908
1912
1916
1920
1924
1928
1932
1936
1940
1944
1948
1952
1956
1960
1964
1968
1972
1976
1980
1984
1988
1992
1996
2000
2004
2008
2012



Predicting Current/Future Climate Change Risk Event Probabilities for Fiji MSC's

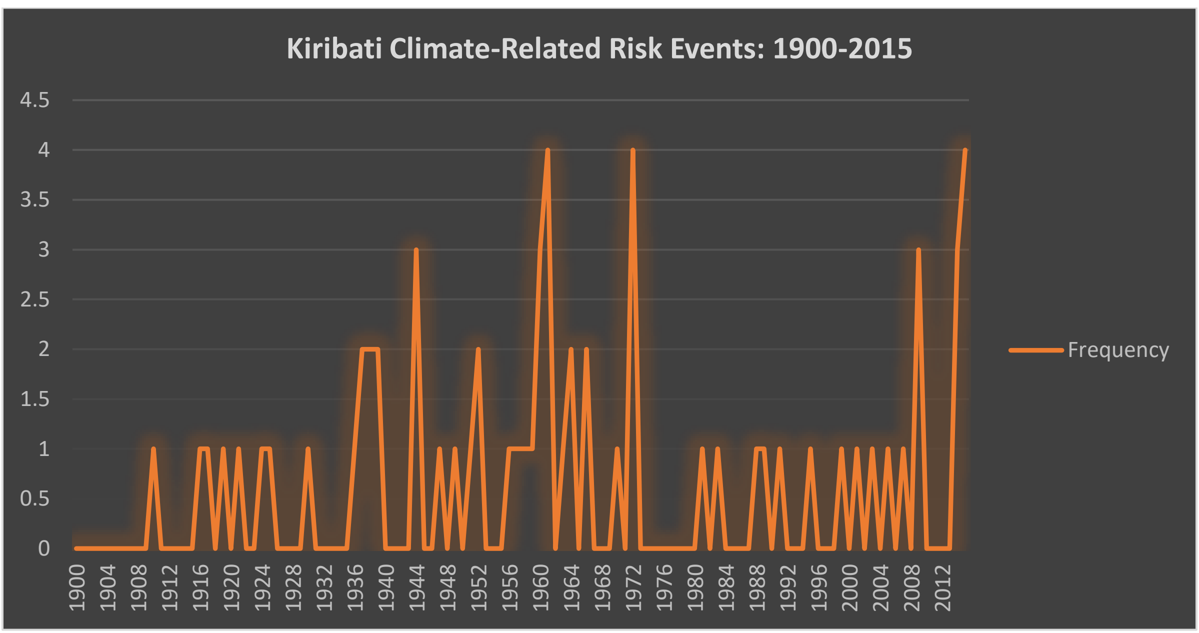
Future	**Current**	**2017**	**2018**	**2019**	**2020**		**Current**	**2017**	**2018**	**2019**	**2020**
B =V = 0	λ = 0					**S = 46**	λ =0.4696				
P(X=0)	0	0	0	0	0	P(X=0)	0.6253	0.6173	0.6093	0.6013	0.5933
P(X=1)	0	0	0	0	0	P(X=1)	0.2936	0.3016	0.096	0.3176	0.3256
P(X=2)	0	0	0	0	0	P(X=2)	0.0689	0.0689	0.0689	0.0689	0.0689
P(X=3)	0	0	0	0	0	P(X=3)	0.0108	0.0108	0.0108	0.0108	0.0108
P(X=4)	0	0	0	0	0	P(X=4)	0.001267	0.001267	0.001267	0.001267	0.001267
P(X=5)	0	0	0	0	0	P(X=5)	0.0000119	0.0000119	0.0000119	0.0000119	0.0000119
Future	**Current**	**2017**	**2018**	**2019**	**2020**		**Current**	**2017**	**2018**	**2019**	**2020**
D= 2)	λ = 0.087					**T = 2**	λ = 0.0435				
P(X=0)	0.9187	0.9107	0.9027	0.8947	0.8867	P(X=0)	0.9828	0.9748	0.9668	0.9588	0.9508
P(X=1)	0.07915	0.08715	0.09515	0.10315	0.11115	P(X=1)	0.0171	0.0251	0.0331	0.0411	0.0491
P(X=2)	0.003469	0.003469	0.003469	0.003469	0.003469	P(X=2)	0.0001488	0.0001428	0.0001428	0.0001428	0.0001428
P(X=3)	0.000996	0.000996	0.000996	0.000996	0.000996	P(X=3)	1.854E-07	1.854E-07	1.854E-07	1.854E-07	1.854E-07
P(X=4)	0.00002159	0.00002159	0.00002159	2.159E-05	0.00002159	P(X=4)	3.75E-08	3.75E-08	3.75E-08	3.75E-08	3.75E-08
P(X=5)	3.743E-07	3.743E-07	3.743E-07	3.743E-07	3.743E-07	P(X=5)	1.3061E-11	1.306E-11	1.3061E-11	1.3061E-11	1.3061E-11
Future	**Current**	**2017**	**2018**	**2019**	**2020**		**Current**	**2017**	**2018**	**2019**	**2020**
H (10)	λ = 0.1478					**C= 43**	λ =0.3739				
P(X=0)	λ = 0.087					P(X=0)	0.668	0.66	0.652	0.644	0.636
P(X=1)	0.9187	0.9107	0.9027	0.8947	0.8867	P(X=1)	0.2573	0.2653	0.2733	0.2813	0.2893
P(X=2)	0.07915	0.08715	0.09515	0.10315	0.11115	P(X=2)	0.0481	0.0481	0.0481	0.0481	0.0481
P(X=3)	0.003469	0.003469	0.003469	0.003469	0.003469	P(X=3)	0.005994	0.005994	0.005994	0.005994	0.005994
P(X=4)	0.000996	0.000996	0.000996	0.000996	0.000996	P(X=4)	0.0005603	0.0005603	0.0005603	0.0005603	0.0005603
P(X=5)	0.00002159	0.00002159	0.00002159	0.00002159	0.00002159	P(X=5)	0.0000419	0.0000419	0.0000419	0.0000419	0.0000419
F = 20	λ =0.01739					**G, E = 5**	λ =0.0435				
P(X=0)	0.8404	0.8324	0.8244	0.8164	0.8084	P(X=0)	0.9524	0.9444	0.9364	0.9284	0.9204
P(X=1)	0.1461	0.4241	0.4321	0.4401	0.4481	P(X=1)	0.0416	0.0496	0.0576	0.0656	0.0736
P((X=2)	0.01271	0.01271	0.01271	0.01271	0.01271	P(X=2)	0.0009059	0.0009059	0.0009059	0.0009059	0.0009059
P(X=3)	0.0007366	0.0007366	0.0007366	0.0007366	0.0007366	P(X=3)	1.313E-05	1.313E-05	1.313E-05	1.313E-05	1.313E-05
P(X=4)	0.00003202	0.00003202	0.00003202	0.00003202	0.00003202	P(X=4)	1.428E-07	1.428E-07	1.428E-07	1.428E-07	1.428E-07
P(X=5)	0.00001114	0.00001114	0.00001114	0.00001114	0.00001114	P(X=5)	1.24E-09	1.24E-09	1.24E-09	1.24E-09	1.24E-09

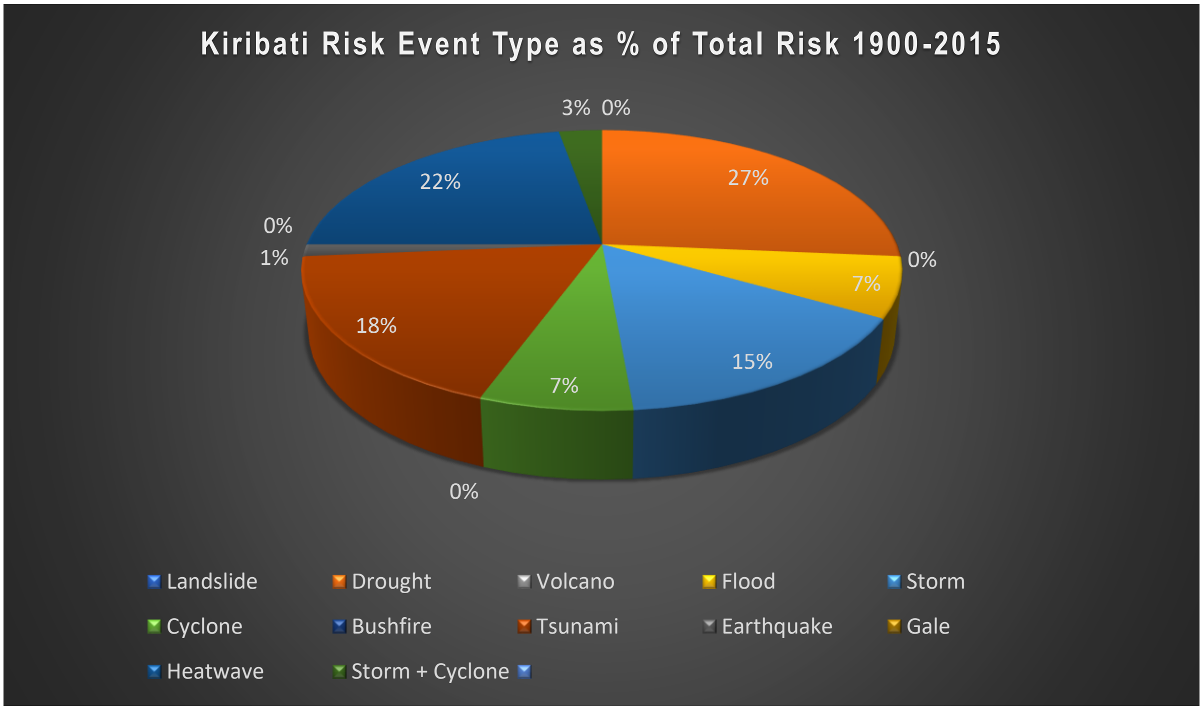
KIRIBATI

Historical Pacific Climate Change Risk Chronology Kiribati		
Year	No of Risk Events	Date (Where Information Available)
1900		
1901		
1902		
1903		
1904		
1905		
1906		
1907		
1908		
1909		
1910	D	
1911		
1912		
1913		
1914		
1915		
1916	D	
1917	D	
1918		
1919	D	
1920		
1921		
1922		
1923		
1924	D	
1925	D	
1926		
1927		
1928		
1929		
1930	S	
1931		
1932		
1933		
1934		
1935		
1936	S	
1937	D, F	
1938	D, F	
1939	D, F	
1940		
1941		
1942		
1943		
1944	S, C, (S+C)	
1945		
1946		

1947	D	
1948		
1949	S	
1950*		
1951	H	
1952	H, T	
1953		
1954		
1955		
1956	D	
1957	T	
1958	H	
1959	H	
1960	H, 2T	
1961	H, S, C, S+C	
1962		
1963	T	
1964	2T	
1965		
1966	2T	
1967		
1968		
1969		
1970	D	
1971		
1972	E, C, S, D	21/12/1972-C
1973		
1974		
1975		
1976	2S	
1977		
1978		
1979		
1980		
1981	H	
1982		
1983	H	
1984		
1985		
1986		
1987		
1988	D	
1989	D	
1990		
1991	C	
1992		
1993		
1994		
1995	H	
1996		
1997		
1998		

1999	D	
2000		
2001	T	
2002		
2003	T	
2004		
2005	H	
2006		
2007	D	
2008		
2009	T, S, D	
2010		
2011		
2012		
2013		
2014	S, F, T	03/03/2014-F
2015	S, C, F, D	13/03/2015





KIRIBATI

Expected Probability of a KIRIBATI Climate Change Related Risk Event 1900-2015					
Total Average No of Events = 66	λ = 0.5739	**Landslides**	λ = 0	**Drought = 19**	λ = 0.1652
P(X=0)	0.5633	P(X=0)	0	P(X=0)	0.8477
P(X=1)	0.3233	P(X=1)	0	P(X=1)	0.1401
P(X=2)	0.0928	P(X=2)	0	P(X=2)	0.0116
P(X=3)	0.01775	P(X=3)	0	P(X=3)	0.000637
P(X=4)	0.002577	P(X=4)	0	P(X=4)	0.0.00002631
P(X=5)	0.0002923	P(X=5)	0	P(X=5)	8.192E-07
Bushfire = 0	**λ = 0**	**Tsunami = 13**	λ = 0.1130	**Earthquake**	λ = 0
P(X=0)	0	P(X=1)	0.1009	P(X=0)	0
P(X=1)	0	P(X=2)	0.05702	P(X=1)	0
P(X=2)	0	P(X=3)	0.0002148	P(X=2)	0
P(X=3)	0	P(X=4)	0.000006068	P(X=3)	0
P(X=4)	0	P(X=5)	1.371E-07	P(X=4)	0
P(X=5)	0			P(X=5)	0

Volcano = 0	λ =0	Flood = 5	λ =0.0435	Storms = 11	λ = 0.0957	Cyclone = 5	λ =0.0435		
P(X=0)	0	P(X=0)	0.9524	P(X=0)	0.9087	P(X=0)	0.9524		
P(X=1)	0	P(X=1)	0.0416	P(X=1)	0.087	P(X=1)	0.0416		
P(X=2)	0	P(X=2)	0.0009059	P(X=2)	0.004161	P(X=2)	0.0009059		
P(X=3)	0	P(X=3)	1.313E-05	P(X=3)	0.0001327	P(X=3)	1.313E-05		
P(X=4)	0	P(X=4)	1.428E-07	P(X=4)	3.176E-06	P(X=4)	1.428E-07		
P(X=5)	0	P(X=5)	1.24E-09	P(X=5)	6.078E-08	P(X=5)	1.24E-09		
Gale	λ = 0	**Heatwave = 10**	λ = 0.087	**S+C = 2**	λ = 0.0174	**F+S = 2**	λ = 0	**C+F= 2**	λ = 0
P(X=0)	0	P(X=0)	0.9187	P(X=0)	0.9828	P(X=0)	0	P(X=0)	0
P(X=1)	0	P(X=1)	0.07915	P(X=1)	0.0171	P(X=1)	0	P(X=1)	0
P(X=2)	0	P(X=2)	0.003469	P(X=2)	0.0001488	P(X=2)	0	P(X=2)	0
P(X=3)	0	P(X=3)	0.000996	P(X=3)	1.854E-07	P(X=3)	0	P(X=3)	0
P(X=4)	0	P(X=4)	0.00002159	P(X=4)	3.75E-08	P(X=4)	0	P(X=4)	0
P(X=5)	0	P(X=5)	3.743E-07	P(X=5)	1.3061E-11	P(X=5)	0	P(X=5)	0

Predicting Future Climate Change Risks Kiribati

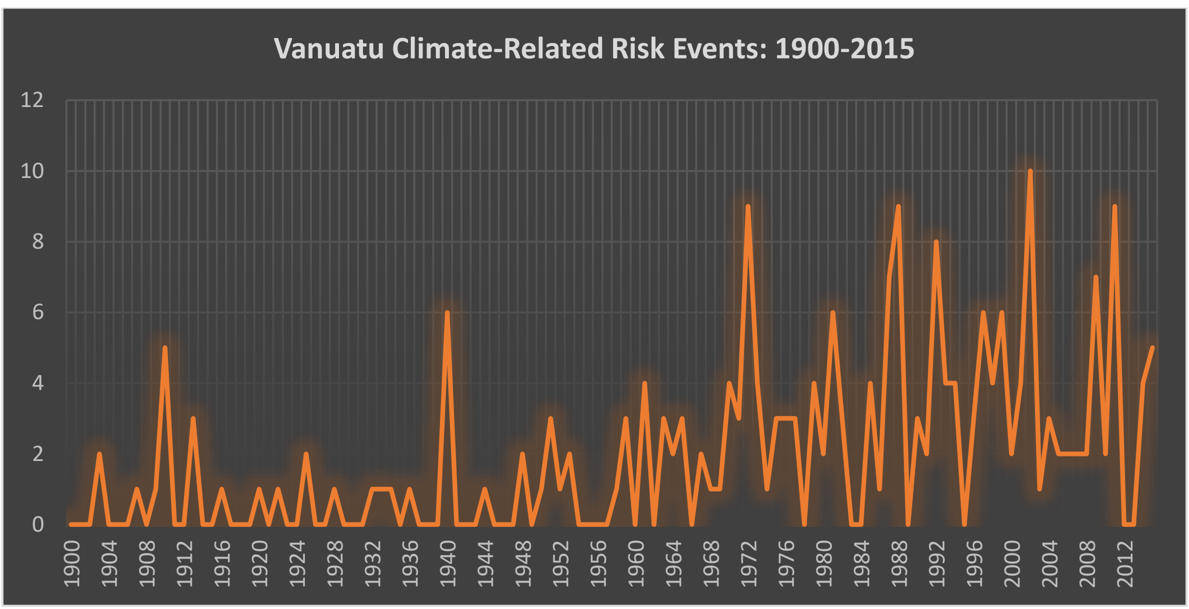
Future	Current	2017	2018	2019	2020		Current	2017	2018	2019	2020
B =V = 0	λ = 0					**S = 11**	λ = 0.0957				
P(X=0)	0	0	0	0	0	P(X=0)	0.9087	0.9007	0.8927	0.8847	0.8767
P(X=1)	0	0	0	0	0	P(X=1)	0.087	0.095	0.103	0.111	0.119
P(X=2)	0	0	0	0	0	P(X=2)	0.004161	0.004161	0.004161	0.004161	0.004161
P(X=3)	0	0	0	0	0	P(X=3)	0.0001327	0.0001327	0.0001327	0.0001327	0.0001327
P(X=4)	0	0	0	0	0	P(X=4)	0.000003176	3.176E-06	0.000003176	3.176E-06	0.000003176
P(X=5)	0	0	0	0	0	P(X=5)	6.078E-08	6.078E-08	6.078E-08	6.078E-08	6.078E-08
Future	**Current**	**2017**	**2018**	**2019**	**2020**	**Current**	**2017**	**2018**	**2019**	**2020**	**Current**
D = 19	λ = 0.1652					**T= 13**	λ = 0.1130				
P(X=0)	0.8477	0.8397	0.8317	0.8237	0.8157	P(X=0)	0.8932	0.8852	0.8772	0.8692	0.8612
P(X=1)	0.1401	0.1481	0.1561	0.1641	0.1721	P(X=1)	0.1009	0.1089	0.1169	0.1249	0.1329
P(X=2)	0.0116	0.0116	0.0116	0.0116	0.0116	P(X=2)	0.05702	0.05702	0.05702	0.05702	0.05702
P(X=3)	0.000637	0.000637	0.000637	0.000637	0.000637	P(X=3)	0.0002148	0.0002148	0.0002148	0.0002148	0.0002148
P(X=4)	0.0.00002631	0.0.00002631	0.0.00002631	0.0.00002631	0.0.00002631	P(X=4)	0.000006068	6.068E-06	0.000006068	6.068E-06	0.000006068
P(X=5)	8.192E-07	8.192E-07	8.192E-07	8.192E-07	8.192E-07	P(X=5)	1.371E-07	1.371E-07	1.371E-07	1.371E-07	1.371E-07
Future	**Current**	**2017**	**2018**	**2019**	**2020**		**Current**	**2017**	**2018**	**2019**	**2020**
H (10)	λ = 0.1478					**C = 5**	λ =0.0435				
P(X=0)	λ = 0.087					P(X=0)	0.9524	0.9444	0.9364	0.9284	0.9204
P(X=1)	0.9187	0.9107	0.9027	0.8947	0.8867	P(X=1)	0.0416	0.0496	0.0576	0.0656	0.0736
P(X=2)	0.07915	0.08715	0.09515	0.10315	0.11115	P(X=2)	0.0009059	0.0009059	0.0009059	0.0009059	0.0009059
P(X=3)	0.003469	0.003469	0.003469	0.003469	0.003469	P(X=3)	0.00001313	0.00001313	0.00001313	0.00001313	0.00001313
P(X=4)	0.000996	0.000996	0.000996	0.000996	0.000996	P(X=4)	1.428E-07	1.428E-07	1.428E-07	1.428E-07	1.428E-07
P(X=5)	0.00002159	0.00002159	0.00002159	0.00002159	0.00002159	P(X=5)	1.24E-09	1.24E-09	1.24E-09	1.24E-09	1.24E-09
Flood = 5	λ =0.0435					**G = 0**	λ = 0				
P(X=0)	0.9524	0.9444	0.9364	0.9284	0.9204	P(X=0)	0	0	0	0	0
P(X=1)	0.0416	0.0496	0.0576	0.0656	0.0736	P(X=1)	0	0	0	0	0
P(X=2)	0.0009059	0.0009059	0.0009059	0.0009059	0.0009059	P(X=2)	0	0	0	0	0
P(X=3)	0.00001313	0.00001313	0.00001313	0.00001313	0.00001313	P(X=3)	0	0	0	0	0
P(X=4)	1.428E-07	1.428E-07	1.428E-07	1.428E-07	1.428E-07	P(X=4)	0	0	0	0	0
P(X=5)	1.24E-09	1.24E-09	1.24E-09	1.24E-09	1.24E-09	P(X=5)	0	0	0	0	0

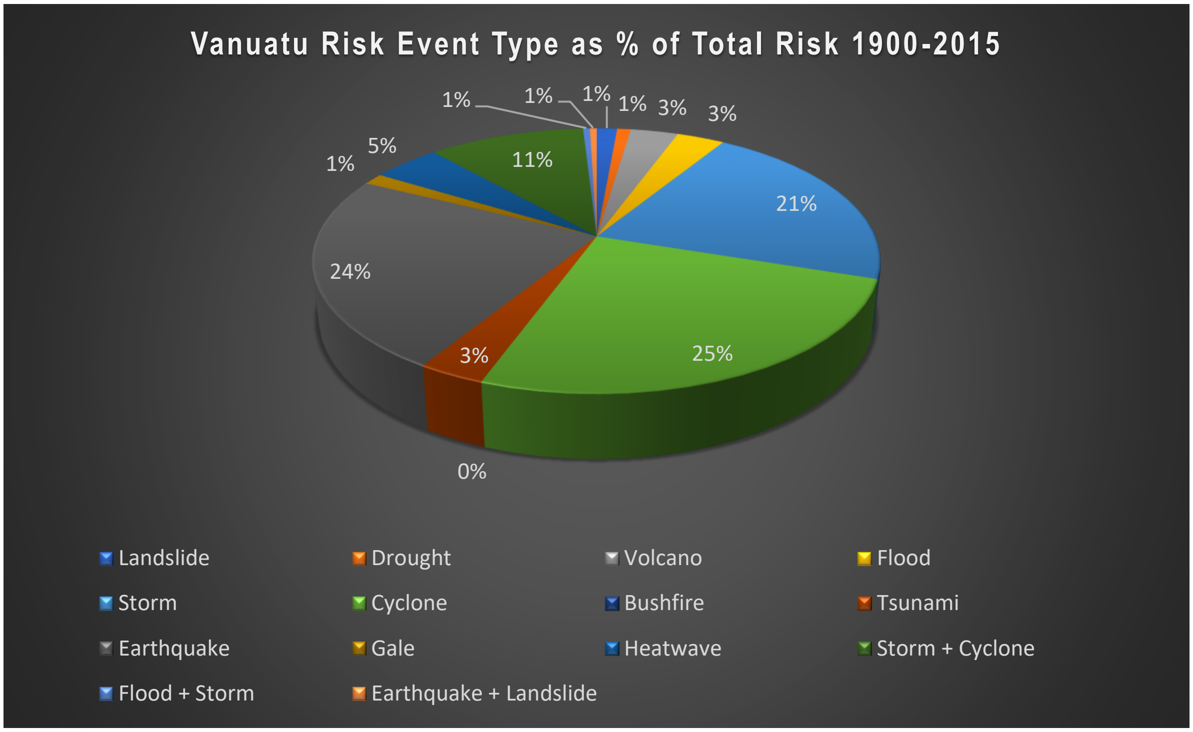
VANUATU

Historical Pacific Climate Change Risk Chronology Vanuatu		
Year	**No of Risk Events**	**Date (Where Information Available)**
1900		
1901		
1902		
1903	S, E	
1904		
1905		
1906		
1907	S	
1908		
1909	E	08/07/1909
1910	S, 4E	01/016/1910; 16/06/1910; 09/11/1910; 10/11/1910;
1911		
1912		
1913	V, 2E	14/10/1913; 10/11/1913;
1914		
1915		
1916	S	
1917		
1918		
1919		
1920	T	
1921		
1922	S	
1923		
1924		
1925	D, E	22/03/1925-E;
1926		
1927		
1928	S	
1929		
1930		
1931		
1932	S	
1933	S	
1934	E	
1935		
1936	S	
1937		
1938		
1939		
1940	2S, 2F, C, S+C	
1941		
1942		
1943		
1944	E	24/11/1944;
1945		
1946		

1947		
1948	S, C	
1949		
1950	E	02/12/1950
1951	S, C, S+C	
1952	E	13/07/1952
1953	2E	02/07/1953;
1954		
1955		
1956		
1957		
1958	T	
1959	S, C, S+C	
1960		
1961	H, T, 2E	23/07/1961
1962		
1963	S, C, S+C	
1964	S, E	05/08/1964
1965	3E	11/08/1965; 12/08/1965; 13/08/1965;
1966		
1967	H, E	
1968	S	
1969	C	11-25/02/1969;
1970	2S, C, E	30-31/12/1970-C;
1971	2C, E	01/01/1971; 29/02-09/03/11972;
1972	3C, 3S, 3 (S+C)	08-26/01/1972; 23/01/1972; 17-23/03/1972;
1973	H, G, 2E,	30/06/1974; 17/08/1974-E
1974	C	30/04-12/05/1974
1975	1S, 2C	4-12/03/1975;
1976	C, S, H	21-26/01/1976;
1977	S, C, S+C,	12-21/01/1977; 16-22/04/1977;
1978		
1979	S, C, S+C, E,	04-12/01/1979; 26/08/1979 –E
1980	C, E	8-15/02/1980; 12/05/1980
1981	2C, 2S, 2(S+C)	31/10-07/11/1981; 19-29/12/1981;
1982	S, C, G	20/01-01/2/1982; 07-12/02/1982 -G;
1983		
1984		
1985	S, C, S+C, E,	21/12/1985
1986	C	07-11/03/1986;
1987	2C, S, S+C, 2E, T	05-14/01/1987; 24/02-11/03/1987; 27/02-08/03/1979; 06/07/1985
1988	2S, 3C, 2(S+C), L, H	24/02-04/03/1988; 23/02-03/03/1988; 07-11/04/1988;
1989		
1990	3E	26/11/1989;
1991	2C	
1992	2S, 2C, 2 (S+C), L, H	25/02-09/03/1992; 05-21/03/1992; 04-17/03/1992;
1993	S, 2C, S+C,	19/01-04/02/1993; 26/03-08/04/1993; 20-27/03/1993;
1994	S, C, 2E	13-18/11/1994;
1995		
1996	2C, H	20-28/03/1996;
1997	3C, E, T, E+T,	03-10/01/1997
1998	C, G, S+C	03-08/01/1998

1999	C, S, E, L, E+L, H	15-22/01/1999; 08/05/1999-S;
2000	C, S	
2001	S, C, S+C, V,	26/02-04/03/2001; 05-11/04/2001; 08/06/2001-V;
2002	4C, S, 2E, F, H, T	26/02-08/03/2002;
2003	C	23-28/02/2003;
2004	C, S, S+C,	05-14/01/2004;
2005	2V	
2006	V, H	
2007	T, E	
2008	V, E	
2009	F, V, 5E	
2010	2E	
2011	F, 2S, 2C, 2(S+C), 2E	05-15/01/2011; 19-28/01/2011; 13-14/02/2011
2012		
2013		
2014	S, F, C, C+F	07-14/03/2014
2015	D, S, F, C, C+F	March





VANUATU

Expected Probability of a Vanuatu Climate Change Related Risk Event 1900-2015					
Total Average No of Events = 218	λ = 1.896	**Landslides = 3**	λ = 0.0261	**Drought = 2**	λ = 0.0174
P(X=0)	0.1512	P(X=0)	0.9742	P(X=0)	0.9828
P(X=1)	0.2847	P(X=1)	0.0254	P(X=1)	0.0171
P(X=2)	0.2699	P(X=2)	0.003318	P(X=2)	0.0001428
P(X=3)	0.1706	P(X=3)	0.00002886	P(X=3)	1.854E-07
P(X=4)	0.0806	P(X=4)	1.883E-07	P(X=4)	3.75E-08
P(X=5)	0.03066	P(X=5)	9.8333E-11	P(X=5)	1.3061E-11
Bushfire = 0	**λ = 0**	**Tsunami = 7**	λ = 0.0609	**Earthquake = 51**	λ = 0.4435
P(X=0)	0	P(X=0)	0.9409	P(X=0)	0.6418
P(X=1)	0	P(X=1)	0.0573	P(X=1)	0.2846
P(X=2)	0	P(X=2)	0.00174	P(X=2)	0.06312
P(X=3)	0	P(X=3)	0.0000354	P(X=3)	0.009331
P(X=4)	0	P(X=4)	5.393E-07	P(X=4)	0.01035
P(X=5)	0	P(X=5)	6.56E-08	P(X=5)	0.00009177

Volcano = 0	**λ =0**	**Flood = 7**	λ = 0.0609	**Storms = 45**	λ = 0.4696	**Cyclone = 55**	λ = 0.4783		
P(X=0)	0	P(X=0)	0.9409	P(X=0)	0.6253	P(X=0)	0.6198		
P(X=1)	0	P(X=1)	0.0573	P(X=1)	0.2936	P(X=1)	0.2965		
P(X=2)	0	P(X=2)	0.00174	P(X=2)	0.0689	P(X=2)	0.0709		
P(X=3)	0	P(X=3)	0.0000354	P(X=3)	0.0108	P(X=3)	0.0113		
P(X=4)	0	P(X=4)	5.393E-07	P(X=4)	0.001267	P(X=4)	0.001352		
P(X=5)	0	P(X=5)	6.56E-08	P(X=5)	0.000119	P(X=5)	0.001293		
Gale = 3	λ = 0.0261	**Heatwave**	λ = 0.0783	**S+C = 23**	λ = 0.0174	**F+S = 2**	λ = 0	**E+L = 1**	λ = 0.0867
P(X=0)	0.9742	P(X=0)	0.9247	P(X=0)	0.9828	P(X=0)	0	P(X=0)	0.9913
P(X=1)	0.0254	P(X=1)	0.0724	P(X=1)	0.0171	P(X=1)	0	P(X=1)	0.0088
P(X=2)	0.003318	P(X=2)	0.002835	P(X=2)	0.0001488	P(X=2)	0	P(X=2)	0.0000375
P(X=3)	0.00002886	P(X=3)	0.00007398	P(X=3)	1.854E-07	P(X=3)	0	P(X=3)	1.088E-06
P(X=4)	1.883E-07	P(X=4)	0.000001448	P(X=4)	3.75E-08	P(X=4)	0	P(X=4)	2.366E-10
P(X=5)	9.8333E-11	P(X=5)	2.267E-07	P(X=5)	1.3061E-11	P(X=5)	0	P(X=5)	4.178E-13

Predicting Future Climate Change Risks Vanuatu

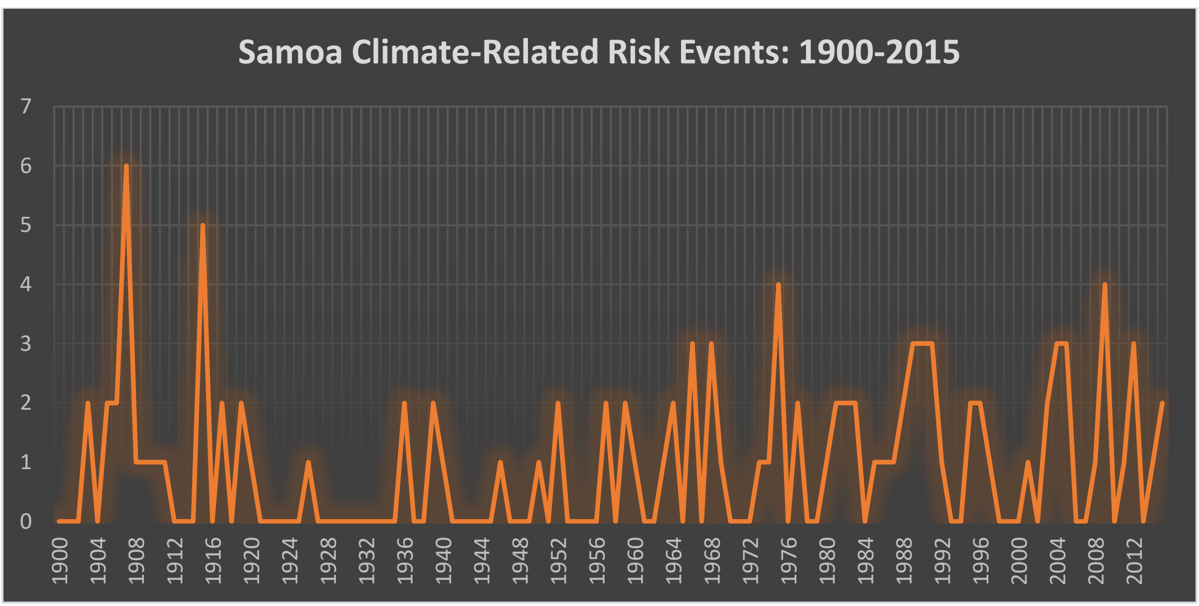
Future	**Current**	**2017**	**2018**	**2019**	**2020**		**Current**	**2017**	**2018**	**2019**	**2020**
B = 0	λ = 0					**S = 45**	λ = 0.4696				
P(X=0)	0	0	0	0	0	P(X=0)	0.6253	0.6173	0.6093	0.6013	0.5933
P(X=1)	0	0	0	0	0	P(X=1)	0.2936	0.3016	0.3096	0.3176	0.3256
P(X=2)	0	0	0	0	0	P(X=2)	0.0689	0.0689	0.0689	0.0689	0.0689
P(X=3)	0	0	0	0	0	P(X=3)	0.0108	0.0108	0.0108	0.0108	0.0108
P(X=4)	0	0	0	0	0	P(X=4)	0.001267	0.001267	0.001267	0.001267	0.001267
P(X=5)	0	0	0	0	0	P(X=5)	0.000119	0.000119	0.000119	0.000119	0.000119
Future	**Current**	**2017**	**2018**	**2019**	**2020**	**Current**	**2017**	**2018**	**2019**	**2020**	**Current**
D = 2	λ = 0.0174					**T, F = 7**	λ = 0.0609				
P(X=0)	0.9828	0.9748	0.9668	0.9588	0.9508	P(X=0)	0.9409	0.9329	0.9249	0.9169	0.9089
P(X=1)	0.0171	0.0251	0.0331	0.0411	0.0491	P(X=1)	0.0573	0.0653	0.0733	0.0813	0.0893
P(X=2)	0.0001428	0.0001428	0.0001428	0.0001428	0.0001428	P(X=2)	0.00174	0.00174	0.00174	0.00174	0.00174
P(X=3)	1.854E-07	1.854E-07	1.854E-07	1.854E-07	1.854E-07	P(X=3)	0.0000354	0.0000354	0.0000354	0.0000354	0.0000354
P(X=4)	3.75E-08	3.75E-08	3.75E-08	3.75E-08	3.75E-08	P(X=4)	5.393E-07	5.393E-07	5.393E-07	5.393E-07	5.393E-07
P(X=5)	1.3061E-11	1.3061E-11	1.3061E-11	1.3061E-11	1.3061E-11	P(X=5)	6.56E-08	6.56E-08	6.56E-08	6.56E-08	6.56E-08
Future	**Current**	**2017**	**2018**	**2019**	**2020**		**Current**	**2017**	**2018**	**2019**	**2020**
H = 9	λ = 0.0783					**C = 55**	λ = 0.4783				
P(X=0)	0.9247	0.9167	0.9087	0.9007	0.8927	P(X=0)	0.6198	0.6118	0.6036	0.5958	0.5878
P(X=1)	0.0724	0.0804	0.0884	0.0964	0.1044	P(X=1)	0.2965	0.3045	0.3125	0.3205	0.3285
P(X=2)	0.002835	0.002835	0.002835	0.002835	0.002835	P(X=2)	0.0709	0.0709	0.0709	0.0709	0.0709
P(X=3)	7.398E-05	0.00007398	0.00007398	7.398E-05	0.00007398	P(X=3)	0.0113	0.0113	0.0113	0.0113	0.0113
P(X=4)	1.448E-06	0.000001448	0.000001448	1.448E-06	0.000001448	P(X=4)	0.001352	0.001352	0.001352	0.001352	0.001352
P(X=5)	2.267E-07	2.267E-07	2.267E-07	2.267E-07	2.267E-07	P(X=5)	0.001293	0.001293	0.001293	0.001293	0.001293
V = 7	λ = 0.0609					**L, G = 3**	λ = 0.0261				
P(X=0)	0.9409	0.9329	0.9249	0.9169	0.9089	P(X=0)	0.9742	0.9662	0.9582	0.9502	0.9422
P(X=1)	0.0573	0.0653	0.0733	0.0813	0.0893	P(X=1)	0.0254	0.0334	0.0414	0.0494	0.0574
P(X=2)	0.00174	0.00174	0.00174	0.00174	0.00174	P(X=2)	0.003318	0.003318	0.003318	0.003318	0.003318
P(X=3)	0.0000354	0.0000354	0.0000354	0.0000354	0.0000354	P(X=3)	2.886E-05	0.00002886	0.00002886	0.00002886	0.00002886
P(X=4)	5.393E-07	5.393E-07	5.393E-07	5.393E-07	5.393E-07	P(X=4)	1.883E-07	1.883E-07	1.883E-07	1.883E-07	1.883E-07
P(X=5)	6.56E-08	6.56E-08	6.56E-08	6.56E-08	6.56E-08	P(X=5)	9.833E-11	9.8333E-11	9.8333E-11	9.8333E-11	9.8333E-11

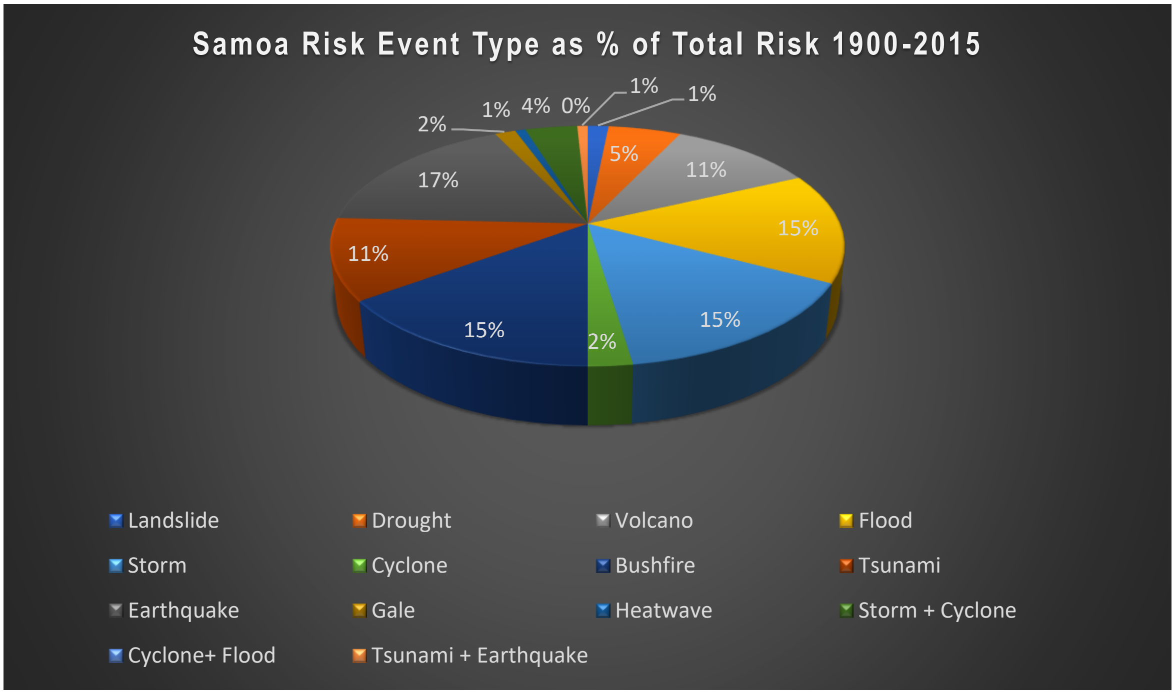
SAMOA

Historical Pacific Climate Change Risk Chronology Samoa		
Year	**No of Risk Events**	**Date (Where Information Available)**
1900		
1901		
1902		
1903	S, C	
1904		
1905	V, T	
1906	V, T	28/11/1906-T;
1907	V, G, 2T, 2E	08/06/1907-T; 19/06/1907-T; 02/07/1907-E; 06/10/1907;
1908	V	
1909	V	
1910	V	
1911	V	
1912		
1913		
1914		
1915	S, C, H, 2T	13/02/1915;
1916		
1917	E, T	26/06/1917
1918		
1919	E, T	
1920	T	09/02/1920
1921		
1922		
1923		
1924		
1925		
1926	S	
1927		
1928		
1929		
1930		
1931		
1932		
1933		
1934		
1935		
1936	S, C	
1937		
1938		
1939	S, F	
1940	C	
1941		
1942		
1943		
1944		
1945		
1946	T	19/04/1946;

1947		
1948		
1949		
1950*	C	
1951		
1952	F, T	07/11/1952-T;
1953		
1954		
1955		
1956		
1957	2E	
1958		
1959	S, F	
1960	T	
1961		
1962		
1963	T,	17/10/1963;
1964	S, E	13/06/1964; 01/04/1964
1965		
1966	S, C, S+C	29/01/1966;
1967		
1968	S, C, S+C	10/02/1968;
1969	C	11-25/02/1969;
1970		
1971		
1972		
1973	S	
1974	F	
1975	C, E, F, T	26/12/1975
1976		
1977	E, T	02/04/1977
1978		
1979		
1980	S	
1981	T, E	01/09/1981;
1982	S, F	September
1983	B, F	
1984		
1985	E	
1986	S	22-26/04/1986
1987	B	
1988	S, G	02-09/01/1988
1989	C, S, C+S	30/01-10/02/1989;
1990	S, C, S+C	27/01-10/02/1990;
1991	S, C, S+C	04-16/12/1991
1992	C	
1993		
1994		
1995	T, E	07/04/1995;
1996	C, D	13-16/01/1996
1997	C	01-08/01/1997
1998		

1999		
2000		
2001	F	15/04/2011
2002		
2003	C, F	25/12/2003
2004	C, S, F	05/01/2004; 16/02/2004;
2005	F, E, T	28/09/2005;
2006		
2007		
2008	F	
2009	E, T, E+T, B	19/03/2009; 28/09/2009;
2010		
2011	B	
2012	S, C, C+F	13/12/2012;
2013		
2014	F	
2015	D, C	March 2015; 13/03/2015;





Volcano = 2	λ = 0.0174	**Flood = 8**	λ =0.0696	**Storms = 22**	λ =0.1913	**Cyclone = 31**	λ =0.2696
P(X=0)	0.9828	P(X=0)	0.9328	P(X=0)	0.8259	P(X=0)	0.7637
P(X=1)	0.0171	P(X=1)	0.0649	P(X=1)	0.158	P(X=1)	2059
P(X=2)	0.0001488	P(X=2)	0.002259	P(X=2)	0.0151	P(X=2)	0.0278
P(X=3)	1.854E-07	P(X=3)	5.241E-05	P(X=3)	0.0009636	P(X=3)	0.002494
P(X=4)	3.75E-08	P(X=4)	9.12E-07	P(X=4)	4.609E-05	P(X=4)	0.0001681
P(X=5)	1.3061E-11	P(X=5)	1.27E-07	P(X=5)	1.763E-05	P(X=5)	9.064E-06
Gale = 3	λ = 0.0261	**Heatwave = 0**	λ = 0	**T+E = 9**	λ =0.0782	**S+C = 13**	λ = 0.1130
P(X=0)	0.9742	P(X=0)	0	P(X=0)	0.9248	P(X=0)	0.8932
P(X=1)	0.0254	P(X=1)	0	P(X=1)	0.0723	P(X=1)	0.1009
P(X=2)	0.003318	P(X=2)	0	P(X=2)	0..002828	P(X=2)	0.05702
P(X=3)	0.00002886	P(X=3)	0	P(X=3)	7.371E-06	P(X=3)	0.0002148
P(X=4)	1.883E-07	P(X=4)	0	P(X=4)	1.441E-07	P(X=4)	6.068E-06
P(X=5)	9.8333E-11	P(X=5)	0	P(X=5)	2.253E-07	P(X=5)	1.371E-07

Predicting Future Climate Change Risks Solomon Islands

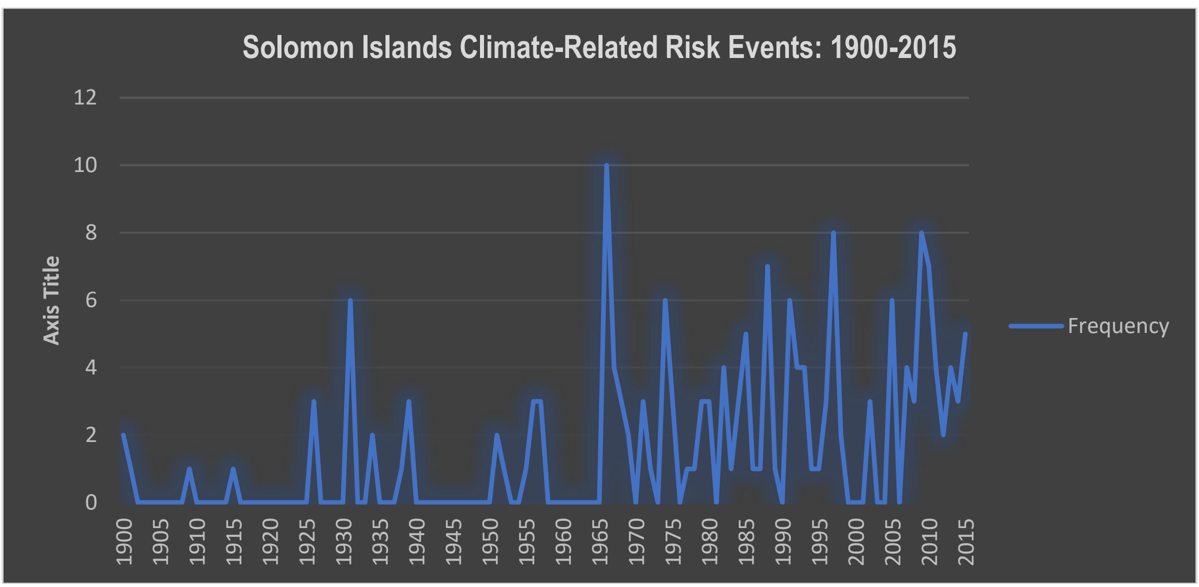
Future	**Current**	**2017**	**2018**	**2019**	**2020**		**Current**	**2017**	**2018**	**2019**	**2020**
B, L, H = 0	λ = 0					**S = 22**	λ =0.1913				
P(X=0)	0	0	0	0	0	P(X=0)	0.8259	0.8179	0.8099	0.8019	0.7939
P(X=1)	0	0	0	0	0	P(X=1)	0.158	0.166	0.174	0.182	0.19
P(X=2)	0	0	0	0	0	P(X=2)	0.0151	0.0151	0.0151	0.0151	0.0151
P(X=3)	0	0	0	0	0	P(X=3)	0.0009636	0.0009636	0.0009636	0.0009636	0.0009636
P(X=4)	0	0	0	0	0	P(X=4)	0.00004609	4.609E-05	0.00004609	4.609E-05	0.00004609
P(X=5)	0	0	0	0	0	P(X=5)	0.00001763	1.763E-05	0.00001763	1.763E-05	0.00001763
Future	**Current**	**2017**	**2018**	**2019**	**2020**	**Current**	**2017**	**2018**	**2019**	**2020**	**Current**
D = 4	λ =0.0348					**T = 25**	λ = 0.1462				
P(X=0)	0.9658	0.9578	0.9498	0.9418	0.9338	P(X=0)	0.864	0.856	0.848	0.84	0.832
P(X=1)	0.0336	0.0416	0.0496	0.0576	0.0656	P(X=1)	0.1263	0.1343	0.1423	0.1503	0.1583
P(X=2)	0.0005846	0.0005846	0.0005846	0.0005846	0.0005846	P(X=2)	0.00923	0.00923	0.00923	0.00923	0.00923
P(X=3)	7.24E-07	0.000000724	0.000000724	0.000000724	0.000000724	P(X=3)	0.0004495	0.0004495	0.0004495	0.0004495	0.0004495
P(X=4)	5.901E-09	5.901E-09	5.901E-09	5.901E-09	5.901E-09	P(X=4)	0.00001645	1.645E-05	0.00001645	1.645E-05	0.00001645
P(X=5)	4.108E-10	4.1077E-10	4.1077E-10	4.1077E-10	4.1077E-10	P(X=5)	4.809E-07	4.809E-07	4.809E-07	4.809E-07	4.809E-07
	Current	**2017**	**2018**	**2019**	**2020**		**Current**	**2017**	**2018**	**2019**	**2020**
V = 2	λ = 0.0174					**C = 31**	λ =0.2696				
P(X=0)	0.9828	0.9748	0.9668	0.9588	0.9508	P(X=0)	0.7637	0.7577	0.7477	0.7397	0.7317
P(X=1)	0.0171	0.0251	0.0331	0.0411	0.0491	P(X=1)	0.2059	0.2139	0.2219	0.2299	0.2379
P(X=2)	0.0001428	0.0001428	0.0001428	0.0001428	0.0001428	P(X=2)	0.0278	0.0278	0.0278	0.0278	0.0278
P(X=3)	1.854E-07	1.854E-07	1.854E-07	1.854E-07	1.854E-07	P(X=3)	0.002494	0.002494	0.002494	0.002494	0.002494
P(X=4)	3.75E-08	3.75E-08	3.75E-08	3.75E-08	3.75E-08	P(X=4)	0.0001681	0.0001681	0.0001681	0.0001681	0.0001681
P(X=5)	1.3061E-11	1.3061E-11	1.306E-11	1.3061E-11	1.306E-11	P(X=5)	9.064E-06	0.000009064	0.000009064	0.000009064	0.000009064
Flood = 8	λ =0.0696					**Gale = 3**	λ = 0.0261				
P(X=0)	0.9328	0.9248	0.9168	0.9088	0.9008	P(X=0)	0.9742	0.9662	0.9582	0.9502	0.9422
P(X=1)	0.0649	0.0729	0.0809	0.0889	0.0969	P(X=1)	0.0254	0.0334	0.0414	0.0494	0.0574
P(X=2)	0.002259	0.002259	0.002259	0.002259	0.002259	P(X=2)	0.003318	0.003318	0.003318	0.003318	0.003318
P(X=3)	5.241E-05	0.00005241	0.00005241	0.00005241	0.00005241	P(X=3)	0.00002886	0.00002886	2.886E-05	0.00002886	2.886E-05
P(X=4)	9.12E-07	0.000000912	0.000000912	0.000000912	0.000000912	P(X=4)	1.883E-07	1.883E-07	1.883E-07	1.883E-07	1.883E-07
P(X=5)	1.27E-07	0.000000127	0.000000127	0.000000127	0.000000127	P(X=5)	9.8333E-11	9.8333E-11	9.833E-11	9.8333E-11	9.833E-11

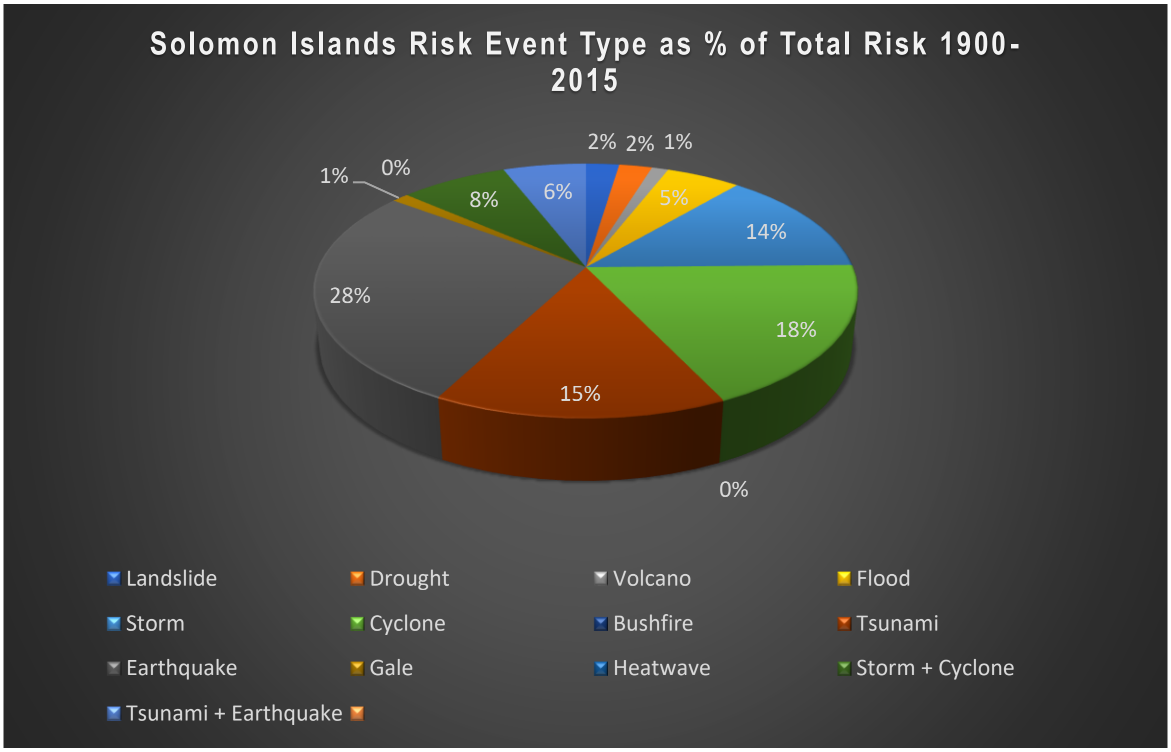
SOLOMON ISLANDS

Historical Pacific Climate Change Risk Chronology Solomon Islands		
Year	**No of Risk Events**	**Date (Where Information Available)**
1900	2E	
1901	E	
1902		
1903		
1904		
1905		
1906		
1907		
1908		
1909	E	09/12/1909
1910		
1911		
1912		
1913		
1914		
1915	T	
1916		
1917		
1918		
1919		
1920		
1921		
1922		
1923		
1924		
1925		
1926	2E, T	12/04/1926; 16/09/1926;
1927		
1928		
1929		
1930		
1931	2E, 2T,2(E+T)	03/10/1931; 10/10/1931
1932		
1933		
1934	2T	18/07/1934; 23/07/1934
1935		
1936		
1937		
1938	E	
1939	E, T, E+T	
1940		
1941		
1942		
1943		
1944		
1945		
1946		

1947		
1948		
1949		
1950*		
1951	C, T	08/11/1950
1952	C	
1953		
1954		
1955	C	
1956	S, C, S+C	
1957	2E, T	04/11/1957
1958		
1959		
1960		
1961		
1962		
1963		
1964		
1965	2E,2T, 2(E+T)	11/08/1965; 13/08/1965
1966	S, C, S+C, F, E,	14/11/1966; 31/12/1966-E
1967	S, C, S+C, F	11/11/1967
1968		
1969	C, E	14-18/04/1969
1970	T	11/08/1970
1971	C, V,	08-26/01/1970
1972	S, C, S+C	23/01/1972; 27-29/03/1972;
1973		
1974	2E, 2T, 2(E+T)	18/06/1974
1975	E, T, E+T	21/07/1975
1976		
1977	E	21/04/1977
1978	E	
1979	S, C, S+C	13/02-06/03/1979;
1980	C, G, E	08/07/1980;
1981		
1982	S, C, S+C, E,	17/07/1982;
1983	S	
1984	3E	07/02/1984; 27/09/1984;
1985	S, C, S+C, E, V	15-22/05/1985;
1986	C	16-22/05/1986;
1987	T	18/06/1987
1988	S, C, S+C, 2E, 2T	
1989	E	
1990		
1991	S, C, 2T, 2E	13-21/11/1991; 09/02/1991-T; 14/10/1991-T
1992	C, S, T, E	27/05/1992;
1993	S, 2C, S+C	28-31/12/1993
1994	C	01/01-20/01/1994;
1995	E	
1996	C, 2S	20-30/12/1996;
1997	S, 2C, 2D, 2T, E	09-13/04/1998; 18-21/11/1997; November 1997-D; 23/04/1997; 29/04/1997;
1998	G, D	August 1998-D

1999		
2000		
2001		
2002	C, S,	28/12/2002;
2003	S+C,	26-28/01/2003
2004		
2005	3C, S, S+C, L	
2006		
2007	E, T, E+T, L	01/04/2007; 02/09/2007
2008	F, 2E	
2009	F, L, 2S, 4E	
2010	2F, S, C, S+C, E, L	9-21/03/2010-C
2011	S, C, S+C, E	26/01-07/02/2011;
2012	F, E	01/02-03/06/2012; 25/12/2012;
2013	E, T, E+T, F	08/02/2003; 02/09/2013-F
2014	C, F, E	08/04/2014-F; 12/04/2014;
2015	D, 2S, C, S+C	March 2015




Solomon Islands Risk Event Type as % of Total Risk 1900-2015
2%
2%
1%
1%
0%
8%
6%
5%
14%
28%
18%
15%
0%
Landslide
Drought
Volcano
Flood
Storm
Cyclone
Bushfire
Tsunami
Earthquake
Gale
Heatwave
Storm + Cyclone
Tsunami + Earthquake

Solomon Islands

Expected Probability of a Solomon Islands Climate Change Related Risk Event 1900-2015					
Total Average No of Events = 170	λ =1.487	**Landslides**	λ = 0	**Drought = 4**	λ =0.0348
P(X=0)	0.226	P(X=0)	0	P(X=0)	0.9658
P(X=1)	0.3361	P(X=1)	0	P(X=1)	0.0336
P(X=2)	0.2499	P(X=2)	0	P(X=2)	0.0005846
P(X=3)	0.1239	P(X=3)	0	P(X=3)	7.24E-07
P(X=4)	0.04065	P(X=4)	0	P(X=4)	5.901E-09
P(X=5)	0.0137	P(X=5)	0	P(X=5)	4.108E-10
Bushfire = 0	**λ = 0**	**Tsunami = 25**	λ = 0.1462	**Earthquake = 47**	λ = 0.4087
P(X=0)	0	P(X=0)	0.864	P(X=0)	0.6645
P(X=1)	0	P(X=1)	0.1263	P(X=1)	0.2716
P(X=2)	0	P(X=2)	0.00923	P(X=2)	0.0555
P(X=3)	0	P(X=3)	0.0004495	P(X=3)	0.007561
P(X=4)	0	P(X=4)	0.00001645	P(X=4)	0.0007725
P(X=5)	0	P(X=5)	4.809E-07	P(X=5)	6.315E-05

Volcano = 2	λ = 0.0174	**Flood = 8**	λ =0.0696	**Storms = 22**	λ =0.1913	**Cyclone = 31**	λ =0.2696
P(X=0)	0.9828	P(X=0)	0.9328	P(X=0)	0.8259	P(X=0)	0.7637
P(X=1)	0.0171	P(X=1)	0.0649	P(X=1)	0.158	P(X=1)	2059
P(X=2)	0.0001488	P(X=2)	0.002259	P(X=2)	0.0151	P(X=2)	0.0278
P(X=3)	1.854E-07	P(X=3)	5.241E-05	P(X=3)	0.0009636	P(X=3)	0.002494
P(X=4)	3.75E-08	P(X=4)	9.12E-07	P(X=4)	4.609E-05	P(X=4)	0.0001681
P(X=5)	1.3061E-11	P(X=5)	1.27E-07	P(X=5)	1.763E-05	P(X=5)	9.064E-06
Gale = 3	λ = 0.0261	**Heatwave = 0**	λ = 0	**T+E = 9**	λ =0.0782	**S+C = 13**	λ = 0.1130
P(X=0)	0.9742	P(X=0)	0	P(X=0)	0.9248	P(X=0)	0.8932
P(X=1)	0.0254	P(X=1)	0	P(X=1)	0.0723	P(X=1)	0.1009
P(X=2)	0.003318	P(X=2)	0	P(X=2)	0..002828	P(X=2)	0.05702
P(X=3)	0.00002886	P(X=3)	0	P(X=3)	7.371E-06	P(X=3)	0.0002148
P(X=4)	1.883E-07	P(X=4)	0	P(X=4)	1.441E-07	P(X=4)	6.068E-06
P(X=5)	9.8333E-11	P(X=5)	0	P(X=5)	2.253E-07	P(X=5)	1.371E-07

Predicting Future Climate Change Risks Solomon Islands

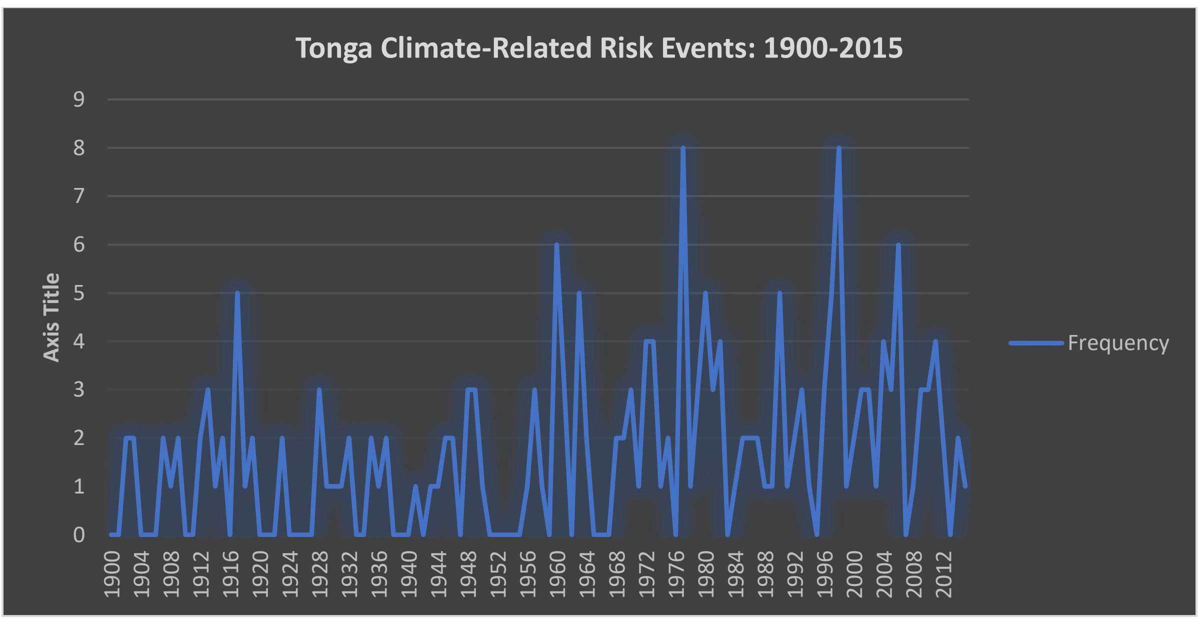
Future	**Current**	**2017**	**2018**	**2019**	**2020**		**Current**	**2017**	**2018**	**2019**	**2020**
B, L, H = 0	λ = 0					**S = 22**	λ =0.1913				
P(X=0)	0	0	0	0	0	P(X=0)	0.8259	0.8179	0.8099	0.8019	0.7939
P(X=1)	0	0	0	0	0	P(X=1)	0.158	0.166	0.174	0.182	0.19
P(X=2)	0	0	0	0	0	P(X=2)	0.0151	0.0151	0.0151	0.0151	0.0151
P(X=3)	0	0	0	0	0	P(X=3)	0.0009636	0.0009636	0.0009636	0.0009636	0.0009636
P(X=4)	0	0	0	0	0	P(X=4)	0.00004609	4.609E-05	0.00004609	4.609E-05	0.00004609
P(X=5)	0	0	0	0	0	P(X=5)	0.00001763	1.763E-05	0.00001763	1.763E-05	0.00001763
Future	**Current**	**2017**	**2018**	**2019**	**2020**	**Current**	**2017**	**2018**	**2019**	**2020**	**Current**
D = 4	λ =0.0348					**T = 25**	λ = 0.1462				
P(X=0)	0.9658	0.9578	0.9498	0.9418	0.9338	P(X=0)	0.864	0.856	0.848	0.84	0.832
P(X=1)	0.0336	0.0416	0.0496	0.0576	0.0656	P(X=1)	0.1263	0.1343	0.1423	0.1503	0.1583
P(X=2)	0.0005846	0.0005846	0.0005846	0.0005846	0.0005846	P(X=2)	0.00923	0.00923	0.00923	0.00923	0.00923
P(X=3)	7.24E-07	0.000000724	0.000000724	0.000000724	0.000000724	P(X=3)	0.0004495	0.0004495	0.0004495	0.0004495	0.0004495
P(X=4)	5.901E-09	5.901E-09	5.901E-09	5.901E-09	5.901E-09	P(X=4)	0.00001645	1.645E-05	0.00001645	1.645E-05	0.00001645
P(X=5)	4.108E-10	4.1077E-10	4.1077E-10	4.1077E-10	4.1077E-10	P(X=5)	4.809E-07	4.809E-07	4.809E-07	4.809E-07	4.809E-07
	Current	**2017**	**2018**	**2019**	**2020**		**Current**	**2017**	**2018**	**2019**	**2020**
V = 2	λ = 0.0174					**C = 31**	λ =0.2696				
P(X=0)	0.9828	0.9748	0.9668	0.9588	0.9508	P(X=0)	0.7637	0.7577	0.7477	0.7397	0.7317
P(X=1)	0.0171	0.0251	0.0331	0.0411	0.0491	P(X=1)	0.2059	0.2139	0.2219	0.2299	0.2379
P(X=2)	0.0001428	0.0001428	0.0001428	0.0001428	0.0001428	P(X=2)	0.0278	0.0278	0.0278	0.0278	0.0278
P(X=3)	1.854E-07	1.854E-07	1.854E-07	1.854E-07	1.854E-07	P(X=3)	0.002494	0.002494	0.002494	0.002494	0.002494
P(X=4)	3.75E-08	3.75E-08	3.75E-08	3.75E-08	3.75E-08	P(X=4)	0.0001681	0.0001681	0.0001681	0.0001681	0.0001681
P(X=5)	1.3061E-11	1.3061E-11	1.306E-11	1.3061E-11	1.306E-11	P(X=5)	9.064E-06	0.000009064	0.000009064	0.000009064	0.000009064
Flood = 8	λ =0.0696					**Gale = 3**	λ = 0.0261				
P(X=0)	0.9328	0.9248	0.9168	0.9088	0.9008	P(X=0)	0.9742	0.9662	0.9582	0.9502	0.9422
P(X=1)	0.0649	0.0729	0.0809	0.0889	0.0969	P(X=1)	0.0254	0.0334	0.0414	0.0494	0.0574
P(X=2)	0.002259	0.002259	0.002259	0.002259	0.002259	P(X=2)	0.003318	0.003318	0.003318	0.003318	0.003318
P(X=3)	5.241E-05	0.00005241	0.00005241	0.00005241	0.00005241	P(X=3)	0.00002886	0.00002886	2.886E-05	0.00002886	2.886E-05
P(X=4)	9.12E-07	0.000000912	0.000000912	0.000000912	0.000000912	P(X=4)	1.883E-07	1.883E-07	1.883E-07	1.883E-07	1.883E-07
P(X=5)	1.27E-07	0.000000127	0.000000127	0.000000127	0.000000127	P(X=5)	9.8333E-11	9.8333E-11	9.833E-11	9.8333E-11	9.833E-11

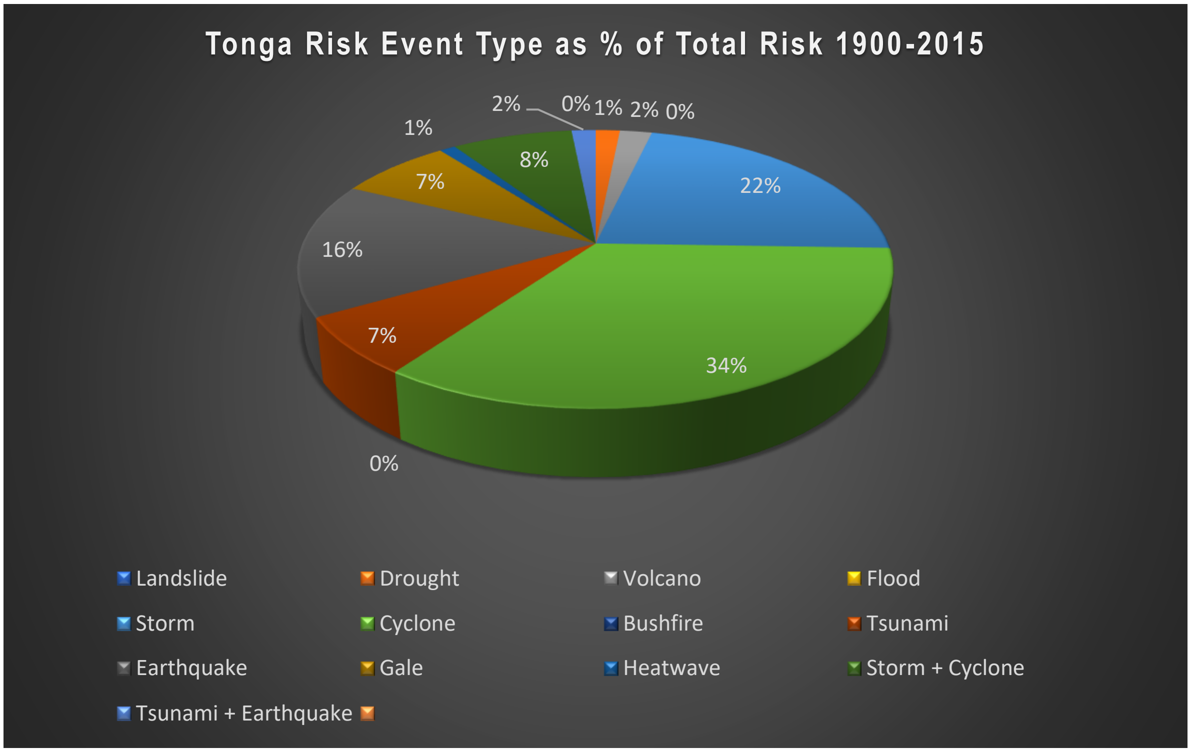
TONGA

Historical Pacific Climate Change Risk Chronology; Tonga		
Year	**No of Risk Events**	**Date (Where Information Available)**
1900		
1901		
1902	2E	
1903	C, E	
1904		
1905		
1906		
1907	T. E	
1908	T	
1909	S, E	
1910		
1911		
1912	S, C	
1913	S, 2E	26/06/1913;
1914	C	
1915	S, C	
1916		
1917	3E, 2 T	
1918	C	
1919	E, T	
1920		
1921		
1922		
1923	2C	
1924		
1925		
1926		
1927		
1928	T, E, C	
1929	V	
1930	C	
1931	C	
1932	S, C	
1933		
1934		
1935	S, C	
1936	C	
1937	S, E	
1938		
1939		
1940		
1941	C	
1942		
1943	V	
1944	C	
1945	S, V	
1946	S, V	

1947		
1948	E, T, E=T	08/09/1948;
1949	S, C, S+C	
1950	E	
1951		
1952		
1953		
1954		
1955		
1956	E	
1957	S, C, S+C	
1958	C	
1959		
1960	2S, 2C, 2(S+C)	
1961	S, C, S+C	
1962		
1963	2S, T, E, (T+E)	18/12/1963-T;
1964	2C	
1965		
1966		
1967		
1968	2C	
1969	2C	
1970	2H, S	
1971	G	
1972	C, 2S, G	
1973	2C, S, S+C	
1974	C	
1975	C, E	
1976		
1977	2S, C, S+C, 2E, 2T	27/06/1977-T; 10/10/1977-T;
1978	S	
1979	2S, C	
1980	S, C, 2G, E	31/01-03/02/1980;
1981	G, 2S	28/02-03/03/1981;
1982	S, C, S+C, E	10/12/1982-E
1983		
1984	S	
1985	S, C	11-14/01/1985;
1986	G, S	
1987	T, E,	
1988	G	
1989	S	30/01-10/02/1989;
1990	S, 2C, S+C, G	
1991	C	
1992	G, S	
1993	2C, S	05-11/02/1993;
1994	G	15-20/01/1994
1995		
1996	G, 2C	12-17/03/1996;
1997	S, 2C, S+C, D	16-19/04/1997;

1998	G, 2S, 2C, 2(S+C), D	02-06/01/1998-C; 23-30/12/1998-C
1999	C	08-13/013/1999
2000	2C	02-08/03/2000;
2001	S, C, S+C,	26/02-04/03/2001;
2002	2C, G	11-14/03/2002; 19/12-31/02/2002; 02/02/2002-G
2003	C	25-31/12/2003
2004	G, S, C, S+C	01-08/01/2004;
2005	G, S, C,	12-14/01/2005-G; 13-15/06/2005
2006	3C, T, 2E	01-07/04/2006; 02-10/04/2006; 03/05/2006-T
2007		
2008	E	
2009	E, T, E+T	19/03/2009-T
2010	2E, C	
2011	S, C, S+C, E	
2012	2C	
2013		
2014	C	
2015	D, C	March 2015; 02-15/01/2015;
2016		





Tonga

Expected Probability of a Tonga Climate Change Related Risk Event 1900-2015					
Total Average No of Events = 192	λ =1.6696	**Landslides**	λ = 0	**Drought = 3**	λ = 0.0261
P(X=0)	0.1883	P(X=0)	0	P(X=0)	0.9742
P(X=1)	0.3144	P(X=1)	0	P(X=1)	0.0254
P(X=2)	0.2625	P(X=2)	0	P(X=2)	0.003318
P(X=3)	0.1461	P(X=3)	0	P(X=3)	2.886E-05
P(X=4)	0.061	P(X=4)	0	P(X=4)	1.883E-07
P(X=5)	0.0204	P(X=5)	0	P(X=5)	9.833E-11
Bushfire = 0	λ = 0	**Tsunami = 13**	λ = 0.1130	**Earthquake = 30**	λ =0.2609
P(X=0)	0	P(X=0)	0.8932	P(X=0)	0.7704
P(X=1)	0	P(X=1)	0.1009	P(X=1)	0.201
P(X=2)	0	P(X=2)	0.05702	P(X=2)	0.02622
P(X=3)	0	P(X=3)	0.0002148	P(X=3)	0.00228
P(X=4)	0	P(X=4)	0.000006068	P(X=4)	0.0001487
P(X=5)	0	P(X=5)	1.371E-07	P(X=5)	0.0000776

TONGA

Volcano = 4	λ =0.0348	Flood = 0	λ = 0	Storms = 42	λ =0.3652	Cyclone = 66	λ =0.513
P(X=0)	0.9658	P(X=0)	0	P(X=0)	0.6941	P(X=0)	0.5987
P(X=1)	0.0336	P(X=1)	0	P(X=1)	0.2535	P(X=1)	0.3071
P(X=2)	0.0005846	P(X=2)	0	P(X=2)	0.04628	P(X=2)	0.07878
P(X=3)	0.000000724	P(X=3)	0	P(X=3)	0.005634	P(X=3)	0.01347
P(X=4)	5.901E-09	P(X=4)	0	P(X=4)	0.0005144	P(X=4)	0.001728
P(X=5)	4.1077E-10	P(X=5)	0	P(X=5)	3.757E-05	P(X=5)	0.0001773
Gale = 14	λ =0.1217	**Heatwave = 2**	λ = 0.0174	**S+C = 15**	λ = 0.1304	**T+E = 2**	λ = 0.0174
P(X=0)	0.8854	P(X=0)	0.9828	P(X=0)	0.8777	P(X=0)	0.9828
P(X=1)	0.1078	P(X=1)	0.0171	P(X=1)	0.1145	P(X=1)	0.0171
P(X=2)	0.006557	P(X=2)	0.0001428	P(X=2)	0.007463	P(X=2)	0.0001488
P(X=3)	0.000266	P(X=3)	1.854E-07	P(X=3)	0.0003244	P(X=3)	1.854E-07
P(X=4)	0.000000805	P(X=4)	3.75E-08	P(X=4)	1.657E-05	P(X=4)	3.75E-08
P(X=5)	0.000000197	P(X=5)	1.306E-11	P(X=5)	2.758E-07	P(X=5)	1.306E-11

Predicting Future Climate Change Risks Tonga

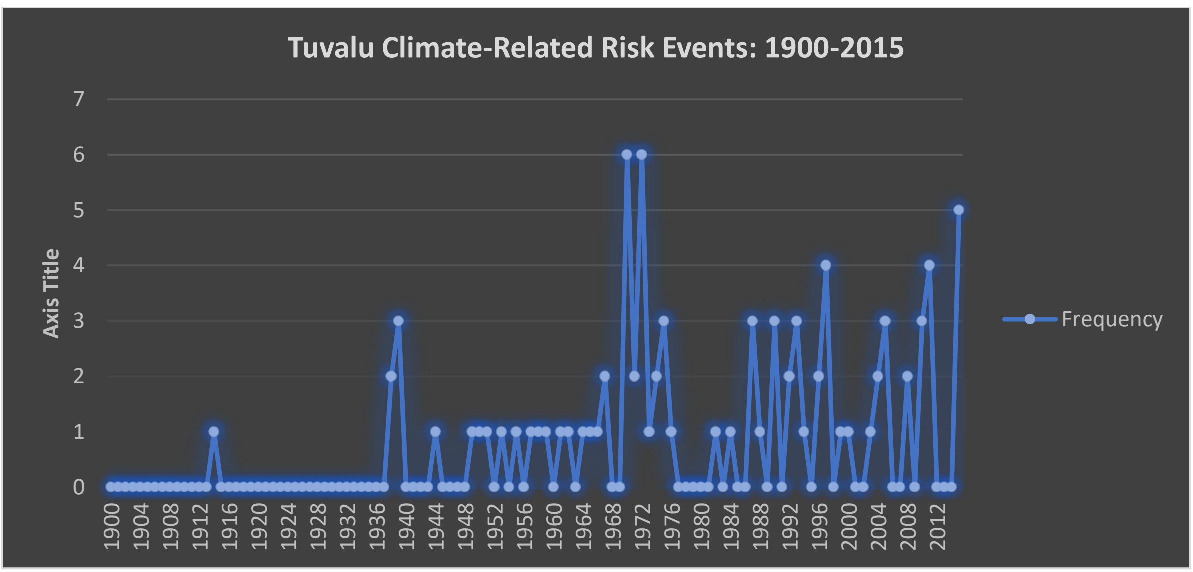
Future	**Current**	**2017**	**2018**	**2019**	**2020**		**Current**	**2017**	**2018**	**2019**	**2020**
L = F = 0	λ = 0					**S = 42**	λ =0.3652				
P(X=0)	0	0	0	0	0	P(X=0)	0.6941	0.6861	0.6781	0.6701	0.6621
P(X=1)	0	0	0	0	0	P(X=1)	0.2535	0.2615	0.2695	0.2775	0.2855
P(X=2)	0	0	0	0	0	P(X=2)	0.04628	0.04628	0.04628	0.04628	0.04628
P(X=3)	0	0	0	0	0	P(X=3)	0.005634	0.005634	0.005634	0.005634	0.005634
P(X=4)	0	0	0	0	0	P(X=4)	0.0005144	0.0005144	0.0005144	0.0005144	0.0005144
P(X=5)	0	0	0	0	0	P(X=5)	0.00003757	0.00003757	0.00003757	3.757E-05	0.00003757
Future	**Current**	**2017**	**2018**	**2019**	**2020**		**Current**	**2017**	**2018**	**2019**	**2020**
D = 3	λ = 0.0261					**C = 66**	λ =0.513				
P(X=0)	0.9742	0.9662	0.9582	0.9502	0.9422	P(X=0)	0.5987	0.5907	0.5827	0.5747	0.5667
P(X=1)	0.0254	0.0334	0.0414	0.0494	0.0574	P(X=1)	0.3071	0.3151	0.3231	0.3311	0.3391
P(X=2)	0.003318	0.003318	0.003318	0.003318	0.003318	P(X=2)	0.07878	0.07878	0.07878	0.07878	0.07878
P(X=3)	0.00002886	0.00002886	0.00002886	0.00002886	0.00002886	P(X=3)	0.01347	0.01347	0.01347	0.01347	0.01347
P(X=4)	1.883E-07	1.883E-07	1.883E-07	1.883E-07	1.883E-07	P(X=4)	0.001728	0.001728	0.001728	0.001728	0.001728
P(X=5)	9.8333E-11	9.8333E-11	9.8333E-11	9.8333E-11	9.8333E-11	P(X=5)	0.0001773	0.0001773	0.0001773	0.0001773	0.0001773
Future	**Current**	**2017**	**2018**	**2019**	**2020**		**Current**	**2017**	**2018**	**2019**	**2020**
H = 2	λ = 0.0174					**E = 30**	λ =0.2609				
P(X=0)	0.9828	0.9748	0.9668	0.9588	0.9508	P(X=0)	0.7704	0.7624	0.7544	0.7464	0.7364
P(X=1)	0.0171	0.0251	0.0331	0.0411	0.0491	P(X=1)	0.201	0.209	0.217	0.225	0.233
P(X=2)	0.0001428	0.0001428	0.0001428	0.0001428	0.0001428	P(X=2)	0.02622	0.02622	0.02622	0.02622	0.02622
P(X=3)	1.854E-07	1.854E-07	1.854E-07	1.854E-07	1.854E-07	P(X=3)	0.00228	0.00228	0.00228	0.00228	0.00228
P(X=4)	3.75E-08	3.75E-08	3.75E-08	3.75E-08	3.75E-08	P(X=4)	0.0001487	0.0001487	0.0001487	0.0001487	0.0001487
P(X=5)	1.306E-11	1.3061E-11	1.3061E-11	1.3061E-11	1.3061E-11	P(X=5)	0.0000776	0.0000776	0.0000776	0.0000776	0.0000776
V= 4	λ =0.0348					**Gale = 14**	λ =0.1217				
P(X=0)	0.9658	0.9578	0.9498	0.9418	0.9338	P(X=0)	0.8854	0.8774	0.8694	0.8614	0.8534
P(X=1)	0.0336	0.0416	0.0496	0.0576	0.0656	P(X=1)	0.1078	0.1158	0.1238	0.1318	0.1398
P(X=2)	0.0005846	0.0005846	0.0005846	0.0005846	0.0005846	P(X=2)	0.006557	0.006557	0.006557	0.006557	0.006557
P(X=3)	7.24E-07	0.000000724	7.24E-07	0.000000724	7.24E-07	P(X=3)	0.000266	0.000266	0.000266	0.000266	0.000266
P(X=4)	5.901E-09	5.901E-09	5.901E-09	5.901E-09	5.901E-09	P(X=4)	8.05E-07	0.000000805	8.05E-07	0.000000805	8.05E-07
P(X=5)	4.108E-10	4.1077E-10	4.108E-10	4.1077E-10	4.108E-10	P(X=5)	1.97E-07	0.000000197	1.97E-07	0.000000197	1.97E-07

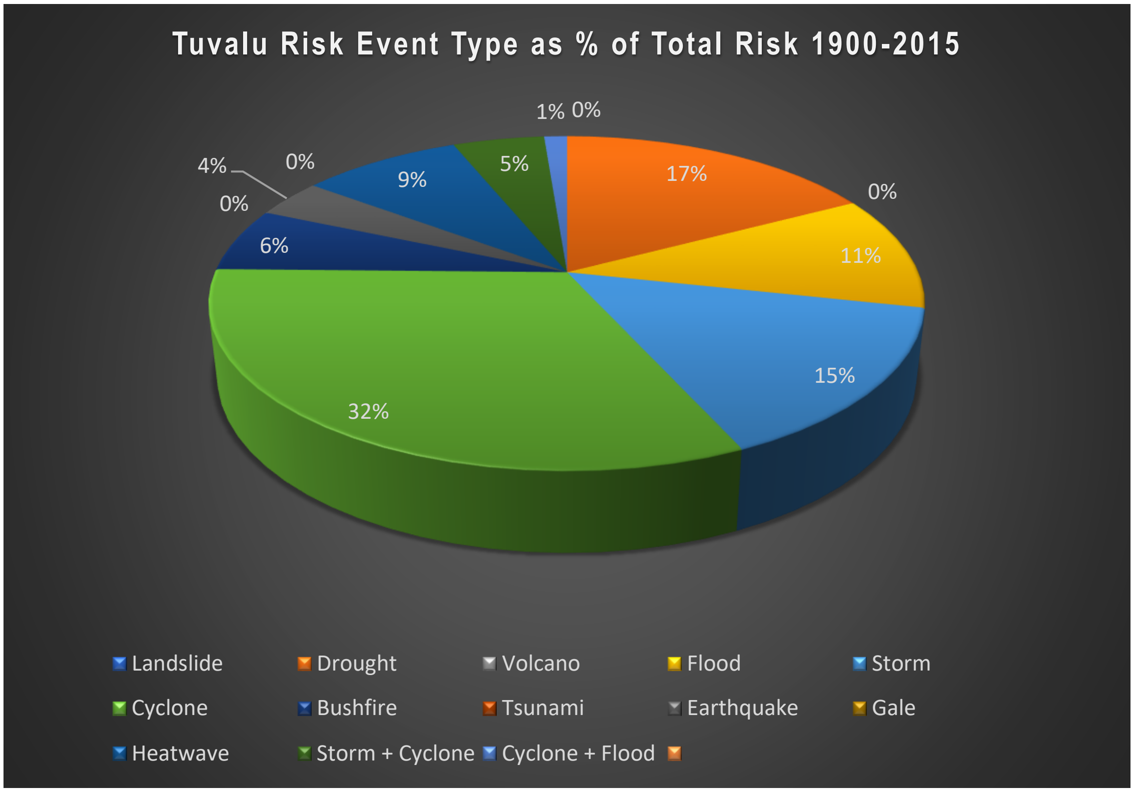
TUVALU

Historical Pacific Climate Change Risk Chronology Tuvalu		
Year	**No of Risk Events**	**Date (Where Information Available)**
1900		
1901		
1902		
1903		
1904		
1905		
1906		
1907		
1908		
1909		
1910		
1911		
1912		
1913		
1914	C	
1915		
1916		
1917		
1918		
1919		
1920		
1921		
1922		
1923		
1924		
1925		
1926		
1927		
1928		
1929		
1930		
1931		
1932		
1933		
1934		
1935		
1936		
1937		
1938	S, F	
1939	B, S, F	
1940		
1941		
1942		
1943		
1944	B	
1945		
1946		

1947		
1948		
1949	D	
1950	D	
1951	D	
1952		
1953		
1954		
1955	F	
1956		
1957	C	
1958	S	
1959	C	
1960		
1961	D	
1962	D	
1963		
1964	D	
1965	C	
1966	C	
1967	B, D	
1968		
1969		
1970	4H, F, S	
1971	C, D	19-28/10/1971
1972	S, C, S+C, 3H	29/02-09/03/1972;
1973	F	
1974	F, S	
1975	F, S, B	
1976	D	
1977		
1978		
1979		
1980		
1981		
1982	E	
1983		
1984	S	
1985		
1986		
1987	S, C, S+C	
1988	D	
1989		
1990	S, C, S+C	30/01-10/02/199-
1991		
1992	2C	23-31/12/1992
1993	S, 2C	1/01-05/01/1993; 05-14/02/1993;
1994	C	
1995		
1996	2C	02-12/03/1996;
1997	S, 3C	05/03/1997, 12/03/1997; 10/07/1997;
1998		

1999	D	
2000	C	12-15/01/2000
2001		
2002		
2003	C	09-15/06/2003;
2004	C, B	12/01/2004
2005	3C	
2006		
2007		
2008	2E	
2009		
2010	2C, D	
2011	D, T, 2C	
2012		
2013		
2014		
2015	S, C, S+C, C+F, D	





TUVALU

Expected Probability of a Tuvalu Climate Change Related Risk Event 1900-2015					
Total Average No of Events = 81	λ =0.7043	**Landslides**	λ = 0	**Drought = 14**	λ =0.1217
P(X=0)	0.4945	P(X=0)	0	P(X=0)	0.8854
P(X=1)	0.3482	P(X=1)	0	P(X=1)	0.1078
P(X=2)	0.1226	P(X=2)	0	P(X=2)	0.006557
P(X=3)	0.02879	P(X=3)	0	P(X=3)	0.000266
P(X=4)	0.005069	P(X=4)	0	P(X=4)	0.000000805
P(X=5)	0.0007141	P(X=5)	0	P(X=5)	0.000000197
Bushfire = 5	λ =0.0435	**Tsunami**	λ = 0	**Earthquake = 3**	λ = 0.0261
P(X=0)	0.9524	P(X=0)	0	P(X=0)	0.9742
P(X=1)	0.0416	P(X=1)	0	P(X=1)	0.0254
P(X=2)	0.0009059	P(X=2)	0	P(X=2)	0.003318
P(X=3)	0.00001313	P(X=3)	0	P(X=3)	0.00002886
P(X=4)	1.428E-07	P(X=4)	0	P(X=4)	1.883E-07
P(X=5)	1.24E-09	P(X=5)	0	P(X=5)	9.8333E-11

TUVALU

Volcano	λ = 0	**Flood = 9**	λ =0.0783	**Storms = 12**	λ =0.1043	**Cyclone = 26**	λ =0.2261
P(X=0)	0	P(X=0)	0.9248	P(X=0)	0.901	P(X=0)	0.7976
P(X=1)	0	P(X=1)	0.0723	P(X=1)	0.0946	P(X=1)	0.1803
P(X=2)	0	P(X=2)	0.002828	P(X=2)	0.047	P(X=2)	0.0204
P(X=3)	0	P(X=3)	7.371E-06	P(X=3)	0.0017	P(X=3)	0.001537
P(X=4)	0	P(X=4)	1.441E-06	P(X=4)	4.413E-05	P(X=4)	8.686E-05
P(X=5)	0	P(X=5)	2.283E-08	P(X=5)	9.267E-06	P(X=5)	3.928E-06
Gale	λ = 0	**Heatwave = 7**	λ = 0.0609	**S+C = 4**	λ =0.0348	**C+F = 1**	λ = 0.0867
P(X=0)	0	P(X=0)	0.9409	P(X=0)	0.9658	P(X=0)	0.9913
P(X=1)	0	P(X=1)	0.0573	P(X=1)	0.0336	P(X=1)	0.0088
P(X=2)	0	P(X=2)	0.00174	P(X=2)	0.0005846	P(X=2)	0.0000375
P(X=3)	0	P(X=3)	0.0000354	P(X=3)	7.24E-07	P(X=3)	1.088E-06
P(X=4)	0	P(X=4)	5.393E-07	P(X=4)	5.901E-09	P(X=4)	2.366E-10
P(X=5)	0	P(X=5)	6.56E-08	P(X=5)	4.108E-10	P(X=5)	4.178E-13

Predicting Future Climate Change Risks Tuvalu

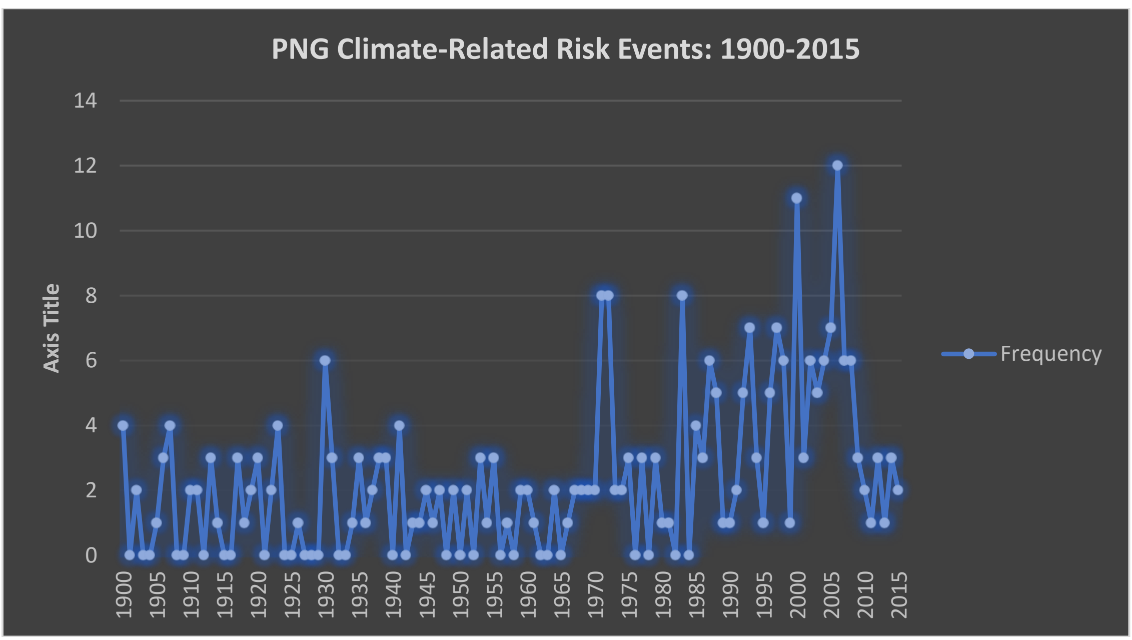
Future	**Current**	**2017**	**2018**	**2019**	**2020**		**Current**	**2017**	**2018**	**2019**	**2020**
L = 0	λ = 0					**S = 12**	λ =0.1043				
P(X=0)	0	0	0	0	0	P(X=0)	0.901	0.893	0.885	0.877	0.869
P(X=1)	0	0	0	0	0	P(X=1)	0.0946	0.1026	0.1106	0.1186	0.1266
P(X=2)	0	0	0	0	0	P(X=2)	0.047	0.047	0.047	0.047	0.047
P(X=3)	0	0	0	0	0	P(X=3)	0.0017	0.0017	0.0017	0.0017	0.0017
P(X=4)	0	0	0	0	0	P(X=4)	0.00004413	0.00004413	0.00004413	0.00004413	0.00004413
P(X=5)	0	0	0	0	0	P(X=5)	0.000009267	0.000009267	0.000009267	0.000009267	0.000009267
Future	**Current**	**2017**	**2018**	**2019**	**2020**	**Current**	**2017**	**2018**	**2019**	**2020**	**Current**
D = 14	λ =0.1217					**C =26**	λ =0.2261				
P(X=0)	0.8854	0.8774	0.8694	0.8614	0.8534	P(X=0)	0.7976	0.7896	0.7816	0.7736	0.7656
P(X=1)	0.1078	0.1158	0.1238	0.1318	0.1398	P(X=1)	0.1803	0.1883	0.1963	0.2043	0.2123
P(X=2)	0.006557	0.006557	0.006557	0.006557	0.006557	P(X=2)	0.0204	0.0204	0.0204	0.0204	0.0204
P(X=3)	0.000266	0.000266	0.000266	0.000266	0.000266	P(X=3)	0.001537	0.001537	0.001537	0.001537	0.001537
P(X=4)	0.000000805	0.000000805	0.000000805	0.000000805	0.000000805	P(X=4)	0.00008686	0.00008686	0.00008686	0.00008686	0.00008686
P(X=5)	0.000000197	0.000000197	0.000000197	0.000000197	0.000000197	P(X=5)	0.000003928	0.000003928	0.000003928	0.000003928	0.000003928
Future	**Current**	**2017**	**2018**	**2019**	**2020**		**Current**	**2017**	**2018**	**2019**	**2020**
H = 7	λ = 0.0609					**T, G = 0**	λ = 0				
P(X=0)	0.9409					P(X=0)	0	0	0	0	0
P(X=1)	0.0573					P(X=1)	0	0	0	0	0
P(X=2)	0.00174	0.00174	0.00174	0.00174	0.00174	P(X=2)	0	0	0	0	0
P(X=3)	0.0000354	0.0000354	0.0000354	0.0000354	0.0000354	P(X=3)	0	0	0	0	0
P(X=4)	5.393E-07	5.393E-07	5.393E-07	5.393E-07	5.393E-07	P(X=4)	0	0	0	0	0
P(X=5)	6.56E-08	6.56E-08	6.56E-08	6.56E-08	6.56E-08	P(X=5)	0	0	0	0	0
Flood = 9	λ =0.0783					**E = 3**	λ = 0.0261				
P(X=0)	0.9247	0.9167	0.9087	0.9007	0.8927	P(X=0)	0.9742	0.9662	0.9582	0.9502	0.9422
P(X=1)	0.0724	0.0804	0.0884	0.0964	0.1044	P(X=1)	0.0254	0.0334	0.0414	0.0494	0.0574
P(X=2)	0.002828	0.002828	0.002828	0.002828	0.002828	P(X=2)	0.003318	0.003318	0.003318	0.003318	0.003318
P(X=3)	0.000007371	0.000007371	0.000007371	0.000007371	0.000007371	P(X=3)	0.00002886	0.00002886	0.00002886	0.00002886	0.00002886
P(X=4)	0.000001441	0.000001441	0.000001441	0.000001441	0.000001441	P(X=4)	1.883E-07	1.883E-07	1.883E-07	1.883E-07	1.883E-07
P(X=5)	2.283E-08	2.283E-08	2.283E-08	2.283E-08	2.283E-08	P(X=5)	9.8333E-11	9.8333E-11	9.8333E-11	9.8333E-11	9.8333E-11

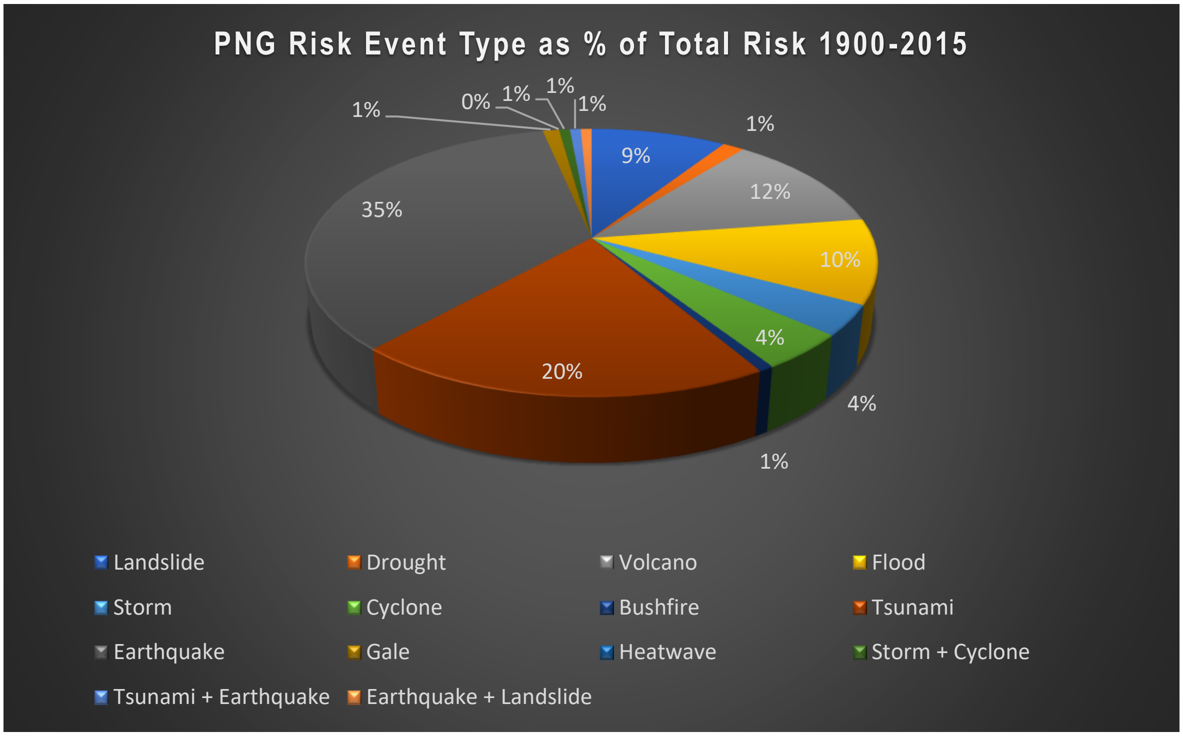
PAPUA NEW GUINEA

Historical Pacific Climate Change Risk Chronology, Papua New Guinea		
Year	**No of Risk Events**	**Date (Where Information Available)**
1900	T, 3E	
1901		
1902	2E	
1903		
1904		
1905	E	
1906	T, 2E	
1907	2T, 2E	
1908		
1909		
1910	T, E	
1911	T, E	08/05/1911;
1912		
1913	T, 2E	11/10/1913-T; 30/03/1913;
1914	V	
1915		
1916	T	03/08/1916
1917	2E,	29/07/1917;
1918	E	
1919	T, E	
1920	2T, E	02/02/1920;
1921		
1922	T, E	
1923	2T, 2E	02/11/1923; 04/11/1923;
1924		
1925		
1926	E	
1927		
1928		
1929		
1930	3E, 2T, E+T	
1931	2E. T	
1932		
1933		
1934	T	
1935	2E, T	
1936	V	
1937	V, T	29/05/1937;
1938	2E, T	06/03/1938; 12/05/1938;
1939	2E, T	30/01/1939;
1940		
1941	2V, T, E	25/05/1941
1942		
1943	V	
1944	E	29/09/1944
1945	2E	28/12/1945
1946	E	29/09/1946

1947	T, E	
1948		
1949	T, E	
1950		
1951	V, E	22/02/1951-E
1952		
1953	2T, E	18/02/1953; 23/04/1953;
1954	V	
1955	2T, E	
1956		
1957	V	02/12/1957
1958		
1959	2E	
1960	V, T	17/05/1960; 11/06/1960
1961	E	
1962		
1963		
1964	T, E	17/12/1964
1965		
1966	E	
1967	T, E	13/08/1967
1968	2E	12/02/1968
1969	T, E	02/08/1969
1970	E, L	31/10/1970; 30/08/1970
1971	L, 4T, 3E	21/03/1971-L;
1972	2C, S, S+C, L, V, B, T	May 1972-C; 28/08/1972-T
1973	2C	
1974	V, T	10/05/1974-T
1975	T, 2E	22/12/1975
1976		
1977	T, 2E	
1978		
1979	L, E, V	18/11/1979-L;
1980	D	October
1981	E	
1982		
1983	2F, V, L, 3E, T	September 1983-F; 15/10/1983-V; 22/04/1983-E
1984	T	27/03/2984
1985	3E,	
1986	L, E, L+E	
1987	L, 3E, 2T	12/10/1987-T; 16/10/1987-T
1988	C, L, 2E, T	01-04/04/1988-C; 06/09/1988
1989	E	10/03/1989
1990	E	
1991	C, L	17-26/12/1991; 06/09/1991-L
1992	G, C, V, 2F	22-27/03/1992-G; 05-14/03/1992 -C;
1993	S, C, F, 2E, L, E+L	14/05/1993-C; 12/06/1993-F; E-13/10/1993; 26-31/12/1993
1994	2V, T,	19/09/1994-V;
1995	E	16/10/1995
1996	G, C, L, 2V	06-29/05/1996-C; 04/10/1998-L;06/10/1993-V; 04/12/1996-V;
1997	2S, C, B, 2D, V	11/03/2997-C; 23/09/1997-B;
1998	2F, E, 2T, E+T	17/07/1998-T

1999	F	
2000	S, F, L, 5E, 2T, V,	17/01/2000; 16/11/2000-E;05/06/2000-E; 10/11/2000-T
2001	G, L, F	26-28/05/2001
2002	3E, L, T, V	10/01/2002; 02/04/2002; 09/09/2002-E; 08/02/2002-T; 02/07/2002-V
2003	3L, 2F	03/05/2003-L; 01/08/2003-L;
2004	3F,2 V, L	October 2004-V
2005	2F, 2E, 3V	E-09/09/2005;
2006	4L, 4V, 4F	13/07/2006-V 07/10/2006-V; 03/02/2006-F; 12/04/2006-F; 27/04/2006-L;
2007	2S, 2C, S+C, F	12/11/2007-S/C
2008	2S, L, F, 2E	06/01/2008-L; 08/12/2008-F;
2009	L, F, E	20/05/2009-L;
2010	F, V	
2011	E	
2012	2F, L	
2013	F	January
2014	S, F, V	April-S, July-F
2015	D, F	04/03/2015-F
2016		





PAPUA NEW GUINEA

Expected Probability of a Papua New Guinea Climate Change Related Risk Event 1900-2015					
Total Average No of Events = 272	λ = 2.3652	**Landslides = 25**	λ = 0.2174	**Drought = 4**	λ =0.0348
P(X=0)	0.09393	P(X=0)	0.8046	P(X=0)	0.9658
P(X=1)	0.2212	P(X=1)	0.1749	P(X=1)	0.0336
P(X=2)	0.2627	P(X=2)	0.0191	P(X=2)	0.0005846
P(X=3)	0.2071	P(X=3)	0.0001378	P(X=3)	0.000000724
P(X=4)	0.1225	P(X=4)	0.00007488	P(X=4)	5.901E-09
P(X=5)	0.05794	P(X=5)	0.00003256	P(X=5)	4.1077E-10
Bushfire = 2	λ = 0.0174	**Tsunami = 53**	λ = 0.4609	**Earthquake = 96**	λ =0.8348
P(X=0)	0.9828	P(X=0)	0.6307	P(X=0)	0.4334
P(X=1)	0.0171	P(X=1)	0.2906	P(X=1)	0.3623
P(X=2)	0.0001488	P(X=2)	0.06699	P(X=2)	0.1512
P(X=3)	1.854E-07	P(X=3)	0.1029	P(X=3)	0.04208
P(X=4)	3.75E-08	P(X=4)	0.001186	P(X=4)	0.008782
P(X=5)	1.3061E-11	P(X=5)	0.0001093	P(X=5)	0.001466

Predicting Future Climate Change Risks Papua New Guinea

Volcano = 33	λ =0.2870	**Flood = 28**	λ = 0.2435	**Storms = 10**	λ = 0.087	**Cyclone = 12**	λ = 0.1043
P(X=0)	0.7505	P(X=0)	0.7839	P(X=0)	0.9187	P(X=0)	0.901
P(X=1)	0.2153	P(X=1)	0.1909	P(X=1)	0.07915	P(X=1)	0.0946
P(X=2)	0.03691	P(X=2)	0.02324	P(X=2)	0.003469	P(X=2)	0.0476
P(X=3)	0.002957	P(X=3)	0.01886	P(X=3)	0.000996	P(X=3)	0.0017
P(X=4)	0.0002122	P(X=4)	0.001148	P(X=4)	2.159E-05	P(X=4)	0.00004463
P(X=5)	0.00001218	P(X=5)	0.000005592	P(X=5)	3.743E-07	P(X=5)	9.267E-07
Gale = 3	λ = 0.0261	**Heatwave = 0**	λ = 0	**S+C = 2**	λ = 0.0174	**T+E = 2**	λ = 0.0174
P(X=0)	0.9742	P(X=0)	0	P(X=0)	0.9828	P(X=0)	0.9828
P(X=1)	0.0254	P(X=1)	0	P(X=1)	0.0171	P(X=1)	0.0171
P(X=2)	0.003318	P(X=2)	0	P(X=2)	0.0001488	P(X=2)	0.0001488
P(X=3)	0.00002886	P(X=3)	0	P(X=3)	1.854E-07	P(X=3)	1.854E-07
P(X=4)	1.883E-07	P(X=4)	0	P(X=4)	3.75E-08	P(X=4)	3.75E-08
P(X=5)	9.8333E-11	P(X=5)	0	P(X=5)	1.3061E-11	P(X=5)	1.306E-11

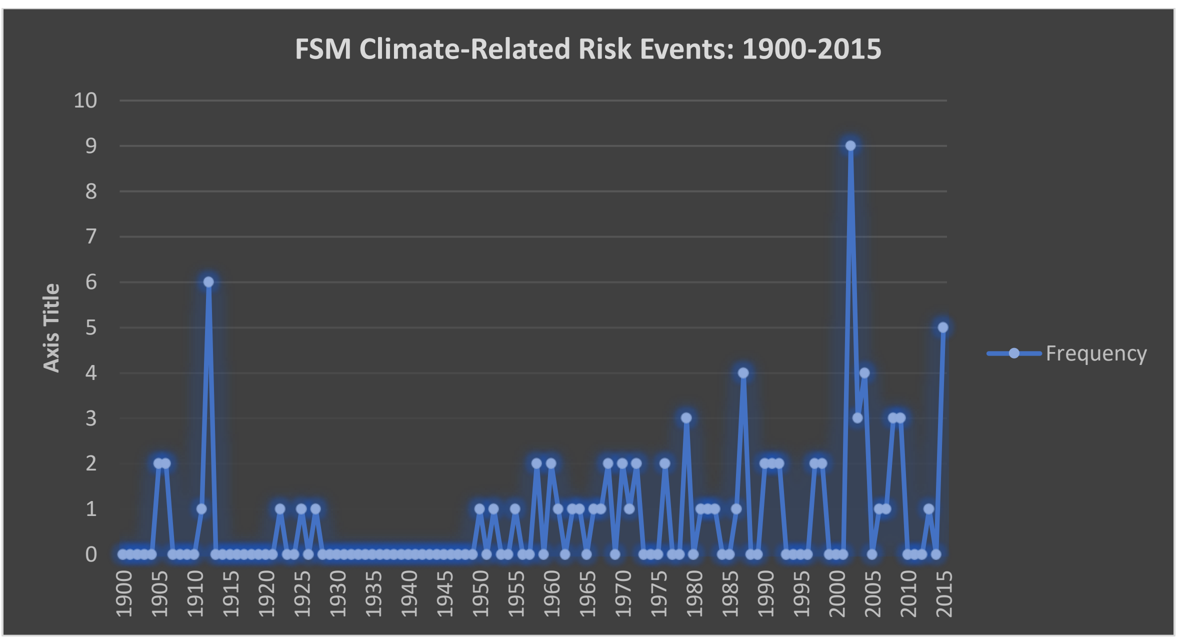
Future	**Current**	**2017**	**2018**	**2019**	**2020**		**Current**	**2017**	**2018**	**2019**	**2020**
H = 0	λ = 0					**S = 10**	λ = 0.087				
P(X=0)	0	0	0	0	0	P(X=0)	0.9187	0.9107	0.9027	0.8947	0.8867
P(X=1)	0	0	0	0	0	P(X=1)	0.07915	0.08715	0.09515	0.10315	0.11115
P(X=2)	0	0	0	0	0	P(X=2)	0.003469	0.003469	0.003469	0.003469	0.003469
P(X=3)	0	0	0	0	0	P(X=3)	0.000996	0.000996	0.000996	0.000996	0.000996
P(X=4)	0	0	0	0	0	P(X=4)	0.00002159	0.00002159	2.159E-05	0.00002159	0.00002159
P(X=5)	0	0	0	0	0	P(X=5)	3.743E-07	3.743E-07	3.743E-07	3.743E-07	3.743E-07
Future	**Current**	**2017**	**2018**	**2019**	**2020**	**Current**	**2017**	**2018**	**2019**	**2020**	**Current**
Drought = 4	λ =0.0348					**Volcano**	λ =0.2870				
P(X=0)	0.9658	0.9578	0.9498	0.9418	0.9338	P(X=0)	0.7505	0.7425	0.7345	0.7265	0.7185
P(X=1)	0.0336	0.0416	0.0496	0.0576	0.0656	P(X=1)	0.2153	0.2233	0.2313	0.2393	0.2473
P(X=2)	0.0005846	0.0005846	0.0005846	0.0005846	0.0005846	P(X=2)	0.03691	0.03691	0.03691	0.03691	0.03691
P(X=3)	0.000000724	7.24E-07	7.24E-07	0.000000724	0.000000724	P(X=3)	0.002957	0.002957	0.002957	0.002957	0.002957
P(X=4)	5.901E-09	5.901E-09	5.901E-09	5.901E-09	5.901E-09	P(X=4)	0.0002122	0.0002122	0.0002122	0.0002122	0.0002122
P(X=5)	4.1077E-10	4.108E-10	4.108E-10	4.1077E-10	4.1077E-10	P(X=5)	1.218E-05	1.218E-05	1.218E-05	1.218E-05	1.218E-05
Future	**Current**	**2017**	**2018**	**2019**	**2020**		**Current**	**2017**	**2018**	**2019**	**2020**
L = 25	λ = 0.2174					**C = 12**	λ = 0.1043				
P(X=0)	0.864	0.856	0.848	0.84	0.832	P(X=0)	0.901	0.893	0.885	0.877	0.869
P(X=1)	0.1263	0.1343	0.1423	0.1503	0.1583	P(X=1)	0.0946	0.1026	0.1106	0.1186	0.1266
P(X=2)	0.0191	0.0191	0.0191	0.0191	0.0191	P(X=2)	0.0476	0.0476	0.0476	0.0476	0.0476
P(X=3)	0.0001378	0.0001378	0.0001378	0.0001378	0.0001378	P(X=3)	0.0017	0.0017	0.0017	0.0017	0.0017
P(X=4)	0.00007488	0.00007488	0.00007488	7.488E-05	0.00007488	P(X=4)	4.463E-05	4.463E-05	0.00004463	0.00004463	4.463E-05
P(X=5)	0.00003256	0.00003256	0.00003256	3.256E-05	0.00003256	P(X=5)	9.267E-07	9.267E-07	9.267E-07	9.267E-07	9.267E-07
T= 53	λ = 0.4609					**E = 96**	λ =0.8348				
P(X=0)	0.6307	0.6227	0.6147	0.6067	0.5987	P(X=0)	0.4334	0.4254	0.4174	0.4094	0.4014
P(X=1)	0.2906	0.2986	0.3066	0.3146	0.3226	P(X=1)	0.3623	0.3703	0.3783	0.3863	0.3943
P(X=2)	0.06699	0.06699	0.06699	0.06699	0.06699	P(X=2)	0.1512	0.1512	0.1512	0.1512	0.1512
P(X=3)	0.1029	0.1029	0.1029	0.1029	0.1029	P(X=3)	0.04208	0.04208	0.04208	0.04208	0.04208
P(X=4)	0.001186	0.001186	0.001186	0.001186	0.001186	P(X=4)	0.008782	0.008782	0.008782	0.008782	0.008782
P(X=5)	0.0001093	0.0001093	0.0001093	0.0001093	0.0001093	P(X=5)	0.001466	0.001466	0.001466	0.001466	0.001466

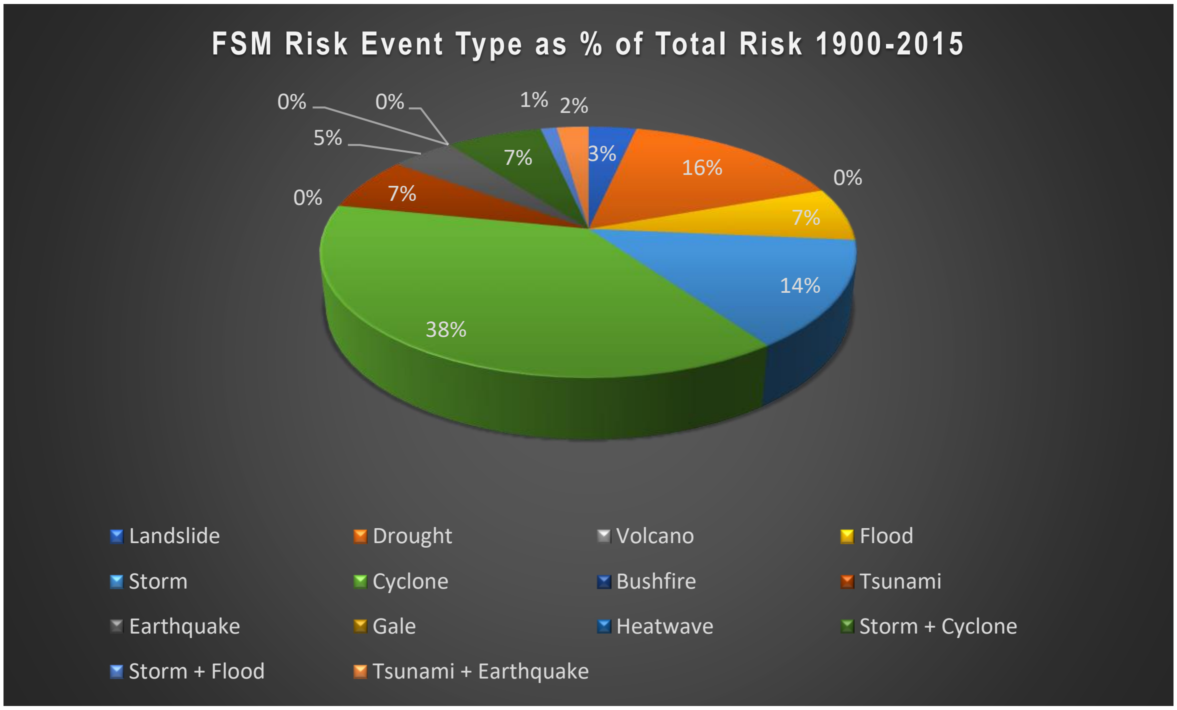
FEDERATED STATES OF MICRONESIA

Historical Pacific Climate Change Risk Chronology Federated States of Micronesia		
Year	No of Risk Events	Date (Where Information Available)
1900		
1901		
1902		
1903		
1904		
1905	C, S	
1906	C, S	
1907		
1908		
1909		
1910		
1911	E	
1912	2E, 2T, 2(T+E)	
1913		
1914		
1915		
1916		
1917		
1918		0
1919		
1920		
1921		
1922	C	
1923		
1924		
1925	T	
1926		
1927	C	
1928		
1929		
1930		
1931		
1932		
1933		
1934		
1935		
1936		
1937		
1938		
1939		
1940		
1941		
1942		
1943		
1944		
1945		
1946		

1947		
1948		
1949		
1950*	S	
1951		
1952	D	
1953		
1954		
1955	D	
1956		
1957		
1958	C, S	
1959		
1960	C, F	
1961	C	
1962		
1963	C	
1964	C	
1965		
1966	D	
1967	C	
1968	C, D	
1969		
1970	C, D	
1971	C	
1972	C, F	
1973		
1974		
1975		
1976	2C	
1977		
1978		
1979	F, T, C	
1980		
1981	C	
1982	D	
1983	D	
1984		
1985		
1986	C	
1987	S, 2C, S+C	
1988		
1989		
1990	C, D	
1991	2C	
1992	C, D	
1993		
1994		
1995		
1996		
1997	L, D	
1998	2D	

1999		
2000		
2001		
2002	3S, 3C, 3(S+C)	
2003	S, C, S+C	
2004	S, C, F, S+F	
2005		
2006	C	
2007	D	
2008	F, T, S	
2009	C, T, F	
2010		
2011		
2012		
2013	C	
2014		
2015	S, 2C, S+C, D	
2016		





FEDERATED STATES OF MICRONESIA

Expected Probability of an FSM Climate Change Related Risk Event 1900-2015					
Total Average No of Events = 87	λ =0.7565	**Landslides = 3**	λ = 0.0261	**Drought = 14**	λ =0.1217
P(X=0)	0.4693	P(X=0)	0.9742	P(X=0)	0.8854
P(X=1)	0.355	P(X=1)	0.0254	P(X=1)	0.1078
P(X=2)	0.1343	P(X=2)	0.003318	P(X=2)	0.006557
P(X=3)	0.03386	P(X=3)	0.00002886	P(X=3)	0.000266
P(X=4)	0.006404	P(X=4)	1.883E-07	P(X=4)	8.05E-07
P(X=5)	0.000969	P(X=5)	9.8333E-11	P(X=5)	1.97E-07
Bushfire	λ = 0	**Tsunami = 6**	λ = 0.05222	**Earthquake = 4**	λ =0.0348
P(X=0)	0	P(X=0)	0.9491	P(X=0)	0.9658
P(X=1)	0	P(X=1)	0.0495	P(X=1)	0.0336
P(X=2)	0	P(X=2)	0.001293	P(X=2)	0.0005846
P(X=3)	0	P(X=3)	0.0000225	P(X=3)	7.24E-07
P(X=4)	0	P(X=4)	2.936E-07	P(X=4)	5.901E-09
P(X=5)	0	P(X=5)	1.91E-10	P(X=5)	4.108E-10

Volcano	λ = 0	Flood = 14	λ =0.1217	Storms = 19	λ = 0.1652	Cyclone = 33	λ = 0.287	S+F = 1	λ = 0.0867
P(X=0)	0	P(X=0)	0.8854	P(X=0)	0.8477	P(X=0)	0.7505	P(X=0)	λ = 0.0867
P(X=1)	0	P(X=1)	0.1078	P(X=1)	0.1401	P(X=1)	0.2154	P(X=1)	0.9913
P(X=2)	0	P(X=2)	0.006557	P(X=2)	0.0116	P(X=2)	0.03091	P(X=2)	0.0088
P(X=3)	0	P(X=3)	0.000266	P(X=3)	0.000637	P(X=3)	0.002957	P(X=3)	0.0000375
P(X=4)	0	P(X=4)	0.000000805	P(X=4)	0.0.00002631	P(X=4)	0.0002122	P(X=4)	1.088E-06
P(X=5)	0	P(X=5)	0.000000197	P(X=5)	8.192E-07	P(X=5)	0.0001218	P(X=5)	2.366E-10
Gale = 0	λ = 0	**Heatwave**	λ = 0	**Flood = 6**	λ = 0.05222	**T+E = 1**	λ = 0.0867	**T+E = 2**	λ = 0.0174
P(X=0)	0	P(X=0)	0	P(X=0)	0.9491	P(X=0)	0.9913	P(X=0)	0.9828
P(X=1)	0	P(X=1)	0	P(X=1)	0.0495	P(X=1)	0.0088	P(X=1)	0.0171
P(X=2)	0	P(X=2)	0	P(X=2)	0.001293	P(X=2)	0.0000375	P(X=2)	0.0001488
P(X=3)	0	P(X=3)	0	P(X=3)	0.0000225	P(X=3)	1.088E-06	P(X=3)	1.854E-07
P(X=4)	0	P(X=4)	0	P(X=4)	2.936E-07	P(X=4)	2.366E-10	P(X=4)	3.75E-08
P(X=5)	0	P(X=5)	0	P(X=5)	1.91E-10	P(X=5)	4.178E-13	P(X=5)	1.306E-11

Predicting Future Climate Change Risks Federated States of Micronesia

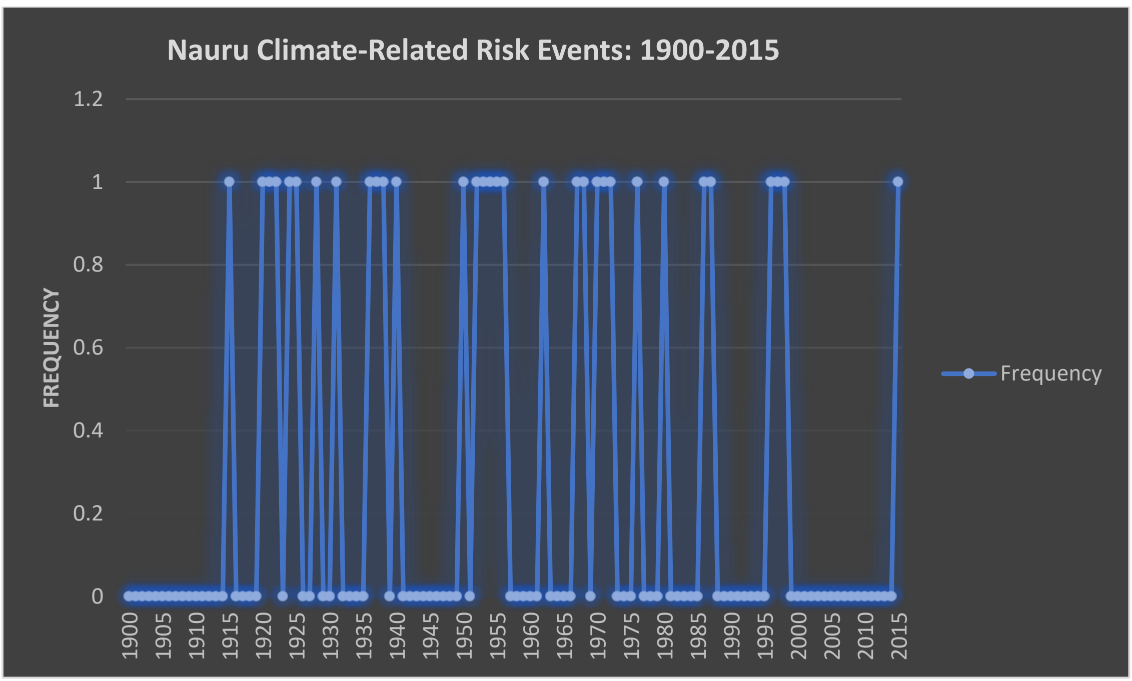
Future	**Current**	**2017**	**2018**	**2019**	**2020**		**Current**	**2017**	**2018**	**2019**	**2020**
B, H, G = 0	λ = 0										
P(X=0)	0	0	0	0	0	**S = 12**	λ =0.1043				
P(X=1)	0	0	0	0	0	P(X=0)	0.901	0.893	0.885	0.877	0.869
P(X=2)	0	0	0	0	0	P(X=1)	0.0946	0.1026	0.1106	0.1186	0.1266
P(X=3)	0	0	0	0	0	P(X=2)	0.047	0.047	0.047	0.047	0.047
P(X=4)	0	0	0	0	0	P(X=3)	0.0017	0.0017	0.0017	0.0017	0.0017
P(X=5)	0	0	0	0	0	P(X=4)	0.00004413	4.413E-05	0.00004413	4.413E-05	0.00004413
Future	**Current**	**2017**	**2018**	**2019**	**2020**	**Current**	**2017**	**2018**	**2019**	**2020**	**Current**
D = 14	λ =0.1217				**Drought = 14**	**E = 4**	λ =0.0348				
P(X=0)	0.8854	0.8774	0.8694	0.8614	P(X=0)	P(X=0)	0.9658	0.9578	0.9498	0.9418	0.9338
P(X=1)	0.1078	0.1158	0.1238	0.1318	P(X=1)	P(X=1)	0.0336	0.0416	0.0496	0.0576	0.0656
P(X=2)	0.006557	0.006557	0.006557	0.006557	P(X=2)	P(X=2)	0.0005846	0.0005846	0.0005846	0.0005846	0.0005846
P(X=3)	0.000266	0.000266	0.000266	0.000266	P(X=3)	P(X=3)	7.24E-07	0.000000724	0.000000724	0.000000724	0.000000724
P(X=4)	0.000000805	8.05E-07	0.000000805	0.000000805	P(X=4)	P(X=4)	5.901E-09	5.901E-09	5.901E-09	5.901E-09	5.901E-09
P(X=5)	0.000000197	1.97E-07	0.000000197	0.000000197	P(X=5)	P(X=5)	4.108E-10	4.1077E-10	4.1077E-10	4.1077E-10	4.1077E-10
Future	**Current**	**2017**	**2018**	**2019**	**2020**		**Current**	**2017**	**2018**	**2019**	**2020**
L = 3	λ = 0.0261					**C = 33**	λ = 0.287				
P(X=0)	0.9742	0.9662	0.9582	0.9502	0.9422	P(X=0)	0.7505	0.7425	0.7345	0.7265	0.7185
P(X=1)	0.0254	0.0334	0.0414	0.0494	0.0574	P(X=1)	0.2153	0.2233	0.2313	0.2393	0.2473
P(X=2)	0.003318	0.003318	0.003318	0.003318	0.003318	P(X=2)	0.03091	0.03091	0.03091	0.03091	0.03091
P(X=3)	0.00002886	0.00002886	2.886E-05	0.00002886	2.886E-05	P(X=3)	0.002957	0.002957	0.002957	0.002957	0.002957
P(X=4)	1.883E-07	1.883E-07	1.883E-07	1.883E-07	1.883E-07	P(X=4)	0.0002122	0.0002122	0.0002122	0.0002122	0.0002122
P(X=5)	9.8333E-11	9.8333E-11	9.833E-11	9.8333E-11	9.833E-11	P(X=5)	0.0001218	0.0001218	0.0001218	0.0001218	0.0001218
F = 14	λ =0.1217					**V =**	λ = 0				
P(X=0)	0.8854	0.8774	0.8694	0.8614	0.8534	P(X=0)	0.9828	0.9748	0.9668	0.9588	0.9508
P(X=1)	0.1078	0.1158	0.1238	0.1318	0.1398	P(X=1)	0.0171	0.0251	0.0331	0.0411	0.0491
P(X=2)	0.006557	0.006557	0.006557	0.006557	0.006557	P(X=2)	0.0001428	0.0001428	0.0001428	0.0001428	0.0001428
P(X=3)	0.000266	0.000266	0.000266	0.000266	0.000266	P(X=3)	1.854E-07	1.854E-07	1.854E-07	1.854E-07	1.854E-07
P(X=4)	0.000000805	0.000000805	0.000000805	0.000000805	0.000000805	P(X=4)	3.75E-08	3.75E-08	3.75E-08	3.75E-08	3.75E-08
P(X=5)	0.000000197	0.000000197	0.000000197	0.000000197	0.000000197	P(X=5)	1.3061E-11	1.306E-11	1.3061E-11	1.3061E-11	1.306E-11

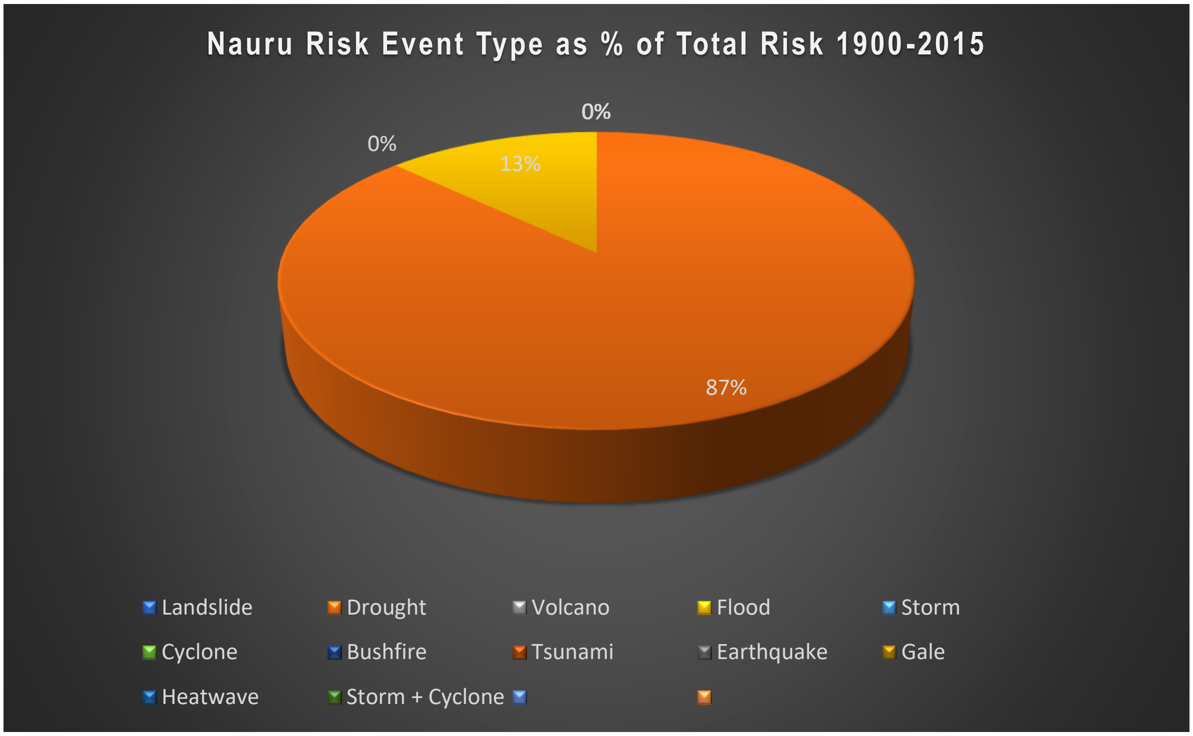
NAURU

Historical Pacific Climate Change Risk Chronology, Nauru		
Year	No of Risk Events	Date (Where Information Available)
1900		
1901		
1902		
1903		
1904		
1905		
1906		
1907		
1908		
1909		
1910		
1911		
1912		
1913		
1914		
1915	D	
1916		
1917		
1918		
1919		
1920	D	
1921	D	
1922	D	
1923		
1924	D	
1925	D	
1926		
1927		
1928	F	
1929		
1930		
1931	D	
1932		
1933		
1934		
1935		
1936	D	
1937	D	
1938	D	
1939		
1940	F	
1941		
1942		
1943		
1944		
1945		
1946		

1947		
1948		
1949		
1950	F	
1951		
1952		
1953	F	
1954	D	
1955	D	
1956	D	
1957		
1958		
1959		
1960		
1961		
1962	D	
1963		
1964		
1965		
1966		
1967	D	
1968	D	
1969		
1970	D	
1971	D	
1972	D	
1973		
1974		
1975		
1976	D	
1977		
1978		
1979		
1980	F	
1981		
1982		
1983		
1984		
1985		
1986	D	
1987	D	
1988		
1989		
1990		
1991		
1992		
1993		
1994		
1995		
1996	D	
1997	D	
1998	D	

1999		
2000		
2001		
2002		
2003		
2004		
2005		
2006		
2007		
2008		
2009		
2010		
2011		
2012		
2013		
2014		
2015	D	





NAURU

Expected Probability of a Nauru Climate Change Related Risk Event 1900-2015					
Total Average No of Events = 31	λ =0.2696	**Landslides**	λ = 0	**Drought = 27**	λ = 0.2348
P(X=0)	0.7637	P(X=0)	0	P(X=0)	0.7907
P(X=1)	0.2059	P(X=1)	0	P(X=1)	0.1857
P(X=2)	0.02775	P(X=2)	0	P(X=2)	0.0218
P(X=3)	0.002494	P(X=3)	0	P(X=3)	0.001706
P(X=4)	0.000168	P(X=4)	0	P(X=4)	0.0001001
P(X=5)	0.000009064	P(X=5)	0	P(X=5)	4.703E-06
Bushfire = 0	λ = 0	**Tsunami = 0**	λ = 0	**Earthquake = 0**	λ = 0
P(X=0)	0	P(X=0)	0	P(X=0) =	0
P(X=1)	0	P(X=1)	0	P(X=1)	0
P(X=2)	0	P(X=2)	0	P(X=2)	0
P(X=3)	0	P(X=3)	0	P(X=3)	0
P(X=4)	0	P(X=4)	0	P(X=4)	0
P(X=5)	0	P(X=5)	0	P(X=5)	0

Predicting Future Climate Change Risks Nauru

Volcano = 0	λ = 0	**Flood = 4**	λ =0.0348	**Storms = 0**	λ = 0	**Cyclone = 0**	λ = 0
P(X=0)	0	P(X=0)	0.9658	P(X=0)	0	P(X=0)	0
P(X=1)	0	P(X=1)	0.0336	P(X=1)	0	P(X=1)	0
P(X=2)	0	P(X=2)	0.0005846	P(X=2)	0	P(X=2)	0
P(X=3)	0	P(X=3)	7.24E-07	P(X=3)	0	P(X=3)	0
P(X=4)	0	P(X=4)	5.901E-09	P(X=4)	0	P(X=4)	0
P(X=5)	0	P(X=5)	4.108E-10	P(X=5)	0	P(X=5)	0
Gale = 0	λ = 0	**Heatwave = 0**	λ = 0	**S+C = 0**	λ = 0	**T+E = 0**	λ = 0
P(X=0)	0	P(X=0)	0	P(X=0)	0	P(X=0)	0
P(X=1)	0	P(X=1)	0	P(X=1)	0	P(X=1)	0
P(X=2)	0	P(X=2)	0	P(X=2)	0	P(X=2)	0
P(X=3)	0	P(X=3)	0	P(X=3)	0	P(X=3)	0
P(X=4)	0	P(X=4)	0	P(X=4)	0	P(X=4)	0
P(X=5)	0	P(X=5)	0	P(X=5)	0	P(X=5)	0

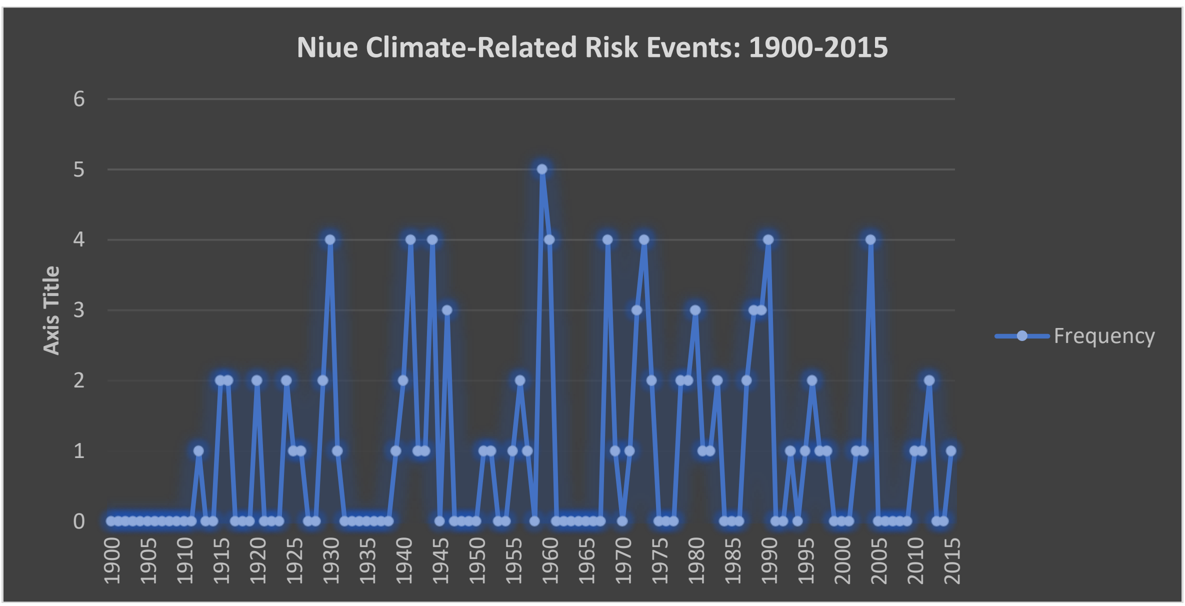
Future	**Current**	**2017**	**2018**	**2019**	**2020**		**Current**	**2017**	**2018**	**2019**	**2020**
L = 0	λ = 0					**S, C = 0**	λ = 0.1652				
P(X=0)	0	0	0	0	0	P(X=0)	0	0	0	0	0
P(X=1)	0	0	0	0	0	P(X=1)	0	0	0	0	0
P(X=2)	0	0	0	0	0	P(X=2)	0	0	0	0	0
P(X=3)	0	0	0	0	0	P(X=3)	0	0	0	0	0
P(X=4)	0	0	0	0	0	P(X=4)	0	0	0	0	0
P(X=5)	0	0	0	0	0	P(X=5)	0	0	0	0	0
Future	**Current**	**2017**	**2018**	**2019**	**2020**	**Current**	**2017**	**2018**	**2019**	**2020**	**Current**
E = 0	λ =					**V = 0**	λ = 0.0609				
P(X=0)	0	0	0	0	0	P(X=0)	0	0	0	0	0
P(X=1)	0	0	0	0	0	P(X=1)	0	0	0	0	0
P(X=2)	0	0	0	0	0	P(X=2)	0	0	0	0	0
P(X=3)	0	0	0	0	0	P(X=3)	0	0	0	0	0
P(X=4)	0	0	0	0	0	P(X=4)	0	0	0	0	0
P(X=5)	0	0	0	0	0	P(X=5)	0	0	0	0	0
Future	**Current**	**2017**	**2018**	**2019**	**2020**		**Current**	**2017**	**2018**	**2019**	**2020**
H = 0	λ = 0					**D = 27**	λ = 0.2348	λ = 0.2348			
P(X=0)	0	0	0	0	0	P(X=0)	0.7907	0.7827	0.7747	0.7667	0.7587
P(X=1)	0	0	0	0	0	P(X=1)	0.1857	0.1937	0.2017	0.2097	0.2177
P(X=2)	0	0	0	0	0	P(X=2)	0.0218	0.0218	0.0218	0.0218	0.0218
P(X=3)	0	0	0	0	0	P(X=3)	0.001706	0.001706	0.001706	0.001706	0.001706
P(X=4)	0	0	0	0	0	P(X=4)	0.0001001	0.0001001	0.0001001	0.0001001	0.0001001
P(X=5)	0	0	0	0	0	P(X=5)	4.703E-06	4.703E-06	4.703E-06	4.703E-06	0.000004703
Flood = 4	λ =0.0348					**G =**	λ = 0				
P(X=0)	0.9658	0.9578	0.9498	0.9418	0.9338	P(X=0)	0	0	0	0	0
P(X=1)	0.0336	0.0416	0.0496	0.0576	0.0656	P(X=1)	0	0	0	0	0
P(X=2)	0.0005846	0.0005846	0.0005846	0.0005846	0.0005846	P(X=2)	0	0	0	0	0
P(X=3)	0.000000724	0.000000724	0.000000724	7.24E-07	7.24E-07	P(X=3)	0	0	0	0	0
P(X=4)	5.901E-09	5.901E-09	5.901E-09	5.901E-09	5.901E-09	P(X=4)	0	0	0	0	0
P(X=5)	4.1077E-10	4.1077E-10	4.1077E-10	4.108E-10	4.108E-10	P(X=5)	0	0	0	0	0

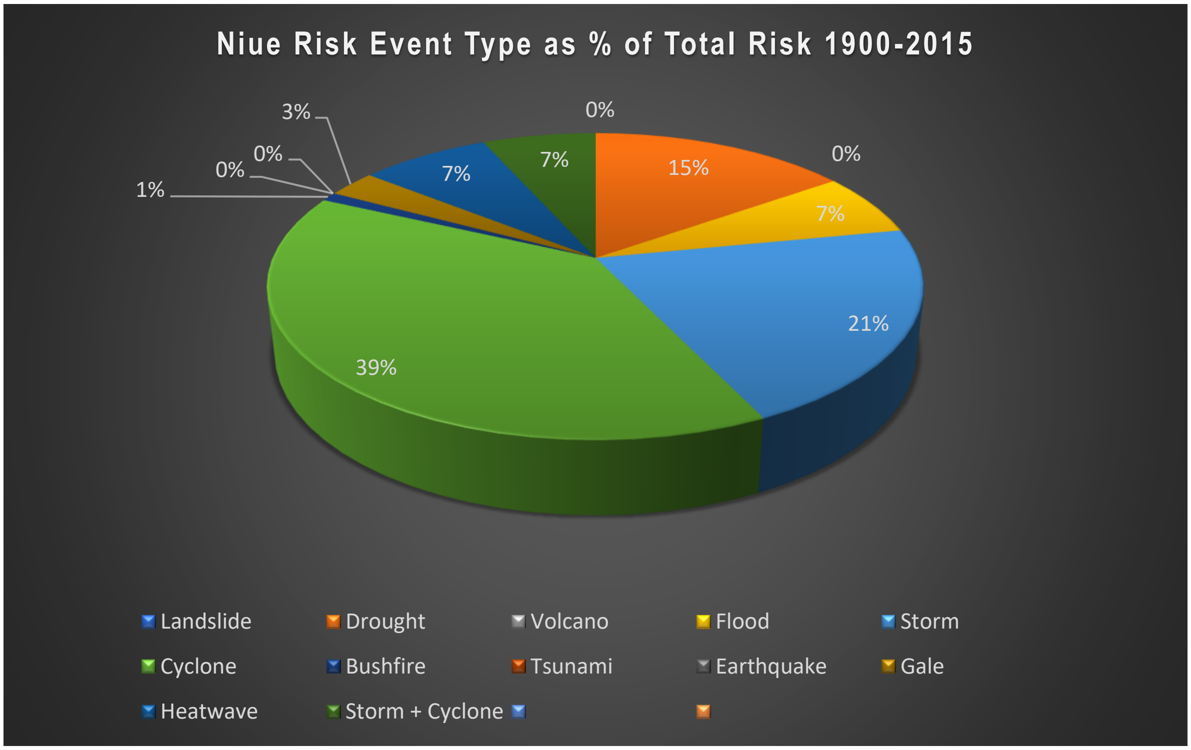
NIUE

Historical Pacific Climate Change Risk Chronology, Niue		
Year	**No of Risk Events**	**Date (Where Information Available)**
1900		
1901		
1902		
1903		
1904		
1905		
1906		
1907		
1908		
1909		
1910		
1911		
1912	D	
1913		
1914		
1915	S, C	
1916	S, F	
1917		
1918		
1919		
1920	S, C	
1921		
1922		
1923		
1924	S, F	
1925	D	
1926	D	
1927		
1928		
1929	S, C	
1930	2S, 2C	
1931	D	
1932		
1933		
1934		
1935		
1936		
1937		
1938		
1939	D	
1940	C, D	
1941	S, C, S+C, D	
1942	D	
1943	D	
1944	S, C, S+C, D	
1945		
1946	S, C, S+C	

1947		
1948		
1949		
1950		
1951	F	
1952	H	
1953		
1954		
1955	C	
1956	2C	
1957	C	
1958		
1959	2S, C, F, D	26/02/1959-C
1960	S, C, S+C, F	
1961		
1962		
1963		
1964		
1965		
1966		
1967		
1968	S, 2C, S+C	18/01/1968;
1969	C	10/02/1969
1970		
1971	G	18-24/01/1971
1972	2C, D	
1973	S, G, C, D	
1974	S, C	
1975		
1976		
1977		
1978	S, F	
1979	C, F	
1980	G, H, S	
1981	C	
1982	D	
1983	C, D	
1984		
1985		
1986		
1987	S, C	22-26/04/1987
1988	S, C, H	
1989	3C	
1990	S, 2C, S+C	04/02/1990; 24/11-04/12/1990;
1991		
1992		
1993	C	
1994		
1995	H	
1996	B, H	
1997	C	02-08/01/1997
1998	C	

1999		
2000		
2001		
2002	C	06-11/02/2002
2003	C	25-31/12/2003
2004	S, 2C, S+C	01/01-08/01/2004;
2005		
2006		
2007		
2008		
2009		
2010	H	
2011	H	
2012	C, D	
2013		
2014		
2015	D	March





NIUE

Expected Probability of a Niue Climate Change Related Risk Event 1900-2015					
Total Average No of Events = 105	λ =0.913	**Landslides**	λ = 0	**Drought = 16**	λ = 0.1391
P(X=0)	0.4013	P(X=0)	0	P(X=0)	0.8701
P(X=1)	0.3664	P(X=1)	0	P(X=1)	0.121
P(X=2)	0.1673	P(X=2)	0	P(X=2)	0.008418
P(X=3)	0.09	P(X=3)	0	P(X=3)	0.003903
P(X=4)	0.01162	P(X=4)	0	P(X=4)	1.357E-05
P(X=5)	0.002122	P(X=5)	0	P(X=5)	3.776E-07
Bushfire = 1	λ = 0.0867	**Tsunami**	λ = 0	**Earthquake**	λ = 0
P(X=0)	0.9913	P(X=0)	0	P(X=0)	0
P(X=1)	0.0088	P(X=1)	0	P(X=1)	0
P(X=2)	0.0000375	P(X=2)	0	P(X=2)	0
P(X=3)	1.088E-06	P(X=3)	0	P(X=3)	0
P(X=4)	2.366E-10	P(X=4)	0	P(X=4)	0
P(X=5)	4.178E-13	P(X=5)	0	P(X=5)	0

Volcano	λ = 0	Flood = 7	λ = 0.0609	Storms = 22	λ =0.1913	Cyclone = 41	λ =0.3565
P(X=0)	0	P(X=0)	0.9409	P(X=0)	0.8259	P(X=0)	0.7001
P(X=1)	0	P(X=1)	0.0573	P(X=1)	0.158	P(X=1)	0.2496
P(X=2)	0	P(X=2)	0.00174	P(X=2)	0.01511	P(X=2)	0.0445
P(X=3)	0	P(X=3)	0.0000354	P(X=3)	0.0009636	P(X=3)	0.005287
P(X=4)	0	P(X=4)	5.393E-07	P(X=4)	4.609E-05	P(X=4)	0.0004712
P(X=5)	0	P(X=5)	6.56E-08	P(X=5)	1.763E-06	P(X=5)	3.36E-07
Gale = 3	λ = 0.0261	**Heatwave = 8**	λ =0.0696	**S+C = 7**	λ = 0.0609	**T+E**	λ = 0
P(X=0)	0.9742	P(X=0)	0.9328	P(X=0)	0.9409	P(X=0)	0
P(X=1)	0.0254	P(X=1)	0.0649	P(X=1)	0.0573	P(X=1)	0
P(X=2)	0.003318	P(X=2)	0.002259	P(X=2)	0.00174	P(X=2)	0
P(X=3)	2.886E-05	P(X=3)	0.00005241	P(X=3)	0.0000354	P(X=3)	0
P(X=4)	1.883E-07	P(X=4)	0.000000912	P(X=4)	5.393E-07	P(X=4)	0
P(X=5)	9.833E-11	P(X=5)	0.000000127	P(X=5)	6.56E-08	P(X=5)	0

Predicting Future Climate Change Risks Niue

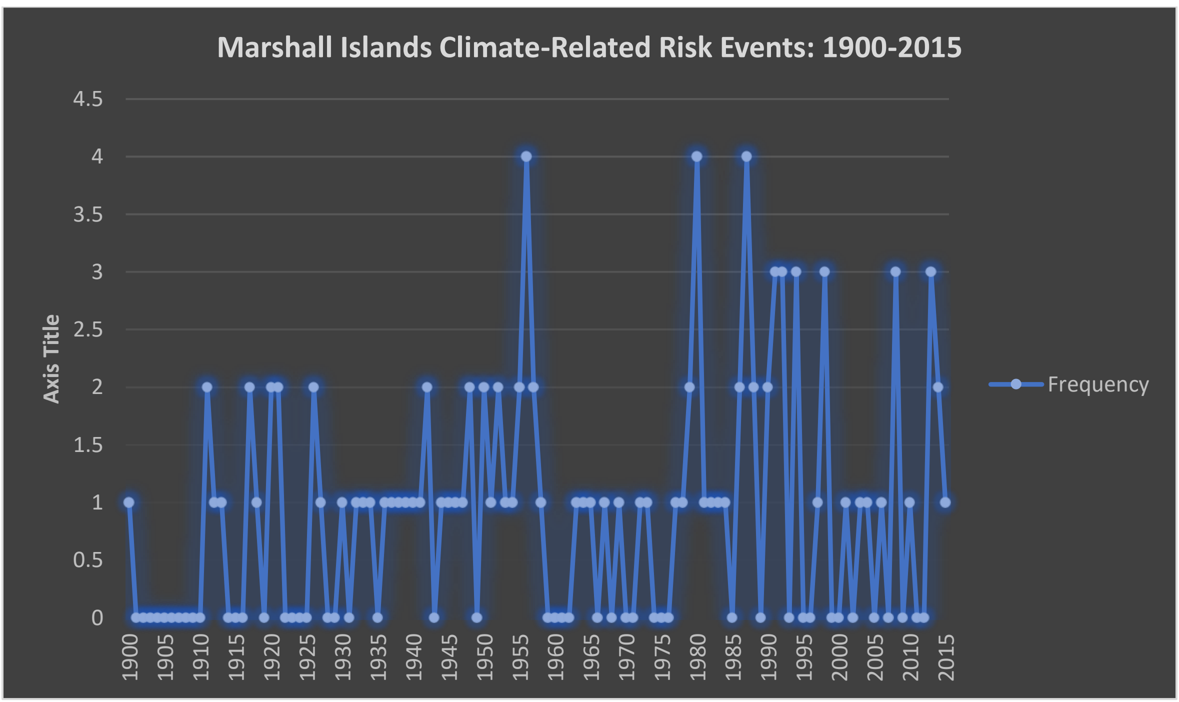
Future	Current	2017	2018	2019	2020		Current	2017	2018	2019	2020
L, T, E = 0	λ = 0					**S = 22**	λ =0.1913				
P(X=0)	0	0	0	0	0	P(X=0)	0.8259	0.8179	0.8099	0.8019	0.7939
P(X=1)	0	0	0	0	0	P(X=1)	0.158	0.166	0.174	0.182	0.19
P(X=2)	0	0	0	0	0	P(X=2)	0.01511	0.01511	0.01511	0.01511	0.01511
P(X=3)	0	0	0	0	0	P(X=3)	0.0009636	0.0009636	0.0009636	0.0009636	0.0009636
P(X=4)	0	0	0	0	0	P(X=4)	0.00004609	0.00004609	4.609E-05	0.00004609	0.00004609
P(X=5)	0	0	0	0	0	P(X=5)	0.000001763	0.000001763	1.763E-06	0.000001763	0.000001763
Future	**Current**	**2017**	**2018**	**2019**	**2020**	**Current**	**2017**	**2018**	**2019**	**2020**	**Current**
D = 16	λ = 0.1391					λ = 0					λ = 0
P(X=0)	0.8701	0.8621	0.8541	0.8461	0.8469	0	0	0	0	0	0
P(X=1)	0.121	0.129	0.137	0.145	0.153	0	0	0	0	0	0
P(X=2)	0.008418	0.008418	0.008418	0.008418	0.008418	0	0	0	0	0	0
P(X=3)	0.003903	0.003903	0.003903	0.003903	0.003903	0	0	0	0	0	0
P(X=4)	0.00001357	1.357E-05	0.00001357	0.00001357	0.00001357	0	0	0	0	0	0
P(X=5)	3.776E-07	3.776E-07	3.776E-07	3.776E-07	3.776E-07	0	0	0	0	0	0
Future	**Current**	**2017**	**2018**	**2019**	**2020**		**Current**	**2017**	**2018**	**2019**	**2020**
H = 8	λ =0.0696					**C = 41**	λ =0.3565				
P(X=0)	0.9328	0.9248	0.9168	0.9088	0.9008	P(X=0)	0.7001	0.6921	0.6841	0.6761	0.6681
P(X=1)	0.0649	0.0729	0.0809	0.0889	0.0969	P(X=1)	0.2496	0.2576	0.2676	0.2736	0.2816
P(X=2)	0.002259	0.002259	0.002259	0.002259	0.002259	P(X=2)	0.0445	0.0445	0.0445	0.0445	0.0445
P(X=3)	5.241E-05	0.00005241	0.00005241	0.00005241	5.241E-05	P(X=3)	0.005287	0.005287	0.005287	0.005287	0.005287
P(X=4)	9.12E-07	0.000000912	0.000000912	0.000000912	9.12E-07	P(X=4)	0.0004712	0.0004712	0.0004712	0.0004712	0.0004712
P(X=5)	1.27E-07	0.000000127	0.000000127	0.000000127	1.27E-07	P(X=5)	3.36E-07	0.000000336	0.000000336	3.36E-07	0.000000336
F = 7	λ = 0.0609					**Gale = 3**	λ = 0.0261				
P(X=0)	0.9409	0.9329	0.9249	0.9169	0.9089	P(X=0)	0.9742	0.9662	0.9582	0.9502	0.9422
P(X=1)	0.0573	0.0653	0.0733	0.0813	0.0893	P(X=1)	0.0254	0.0334	0.0414	0.0494	0.0574
P(X=2)	0.00174	0.00174	0.00174	0.00174	0.00174	P(X=2)	0.003318	0.003318	0.003318	0.003318	0.003318
P(X=3)	0.0000354	0.0000354	0.0000354	0.0000354	0.0000354	P(X=3)	0.00002886	2.886E-05	0.00002886	2.886E-05	0.00002886
P(X=4)	5.393E-07	5.393E-07	5.393E-07	5.393E-07	5.393E-07	P(X=4)	1.883E-07	1.883E-07	1.883E-07	1.883E-07	1.883E-07
P(X=5)	6.56E-08	6.56E-08	6.56E-08	6.56E-08	6.56E-08	P(X=5)	9.8333E-11	9.833E-11	9.8333E-11	9.833E-11	9.8333E-11

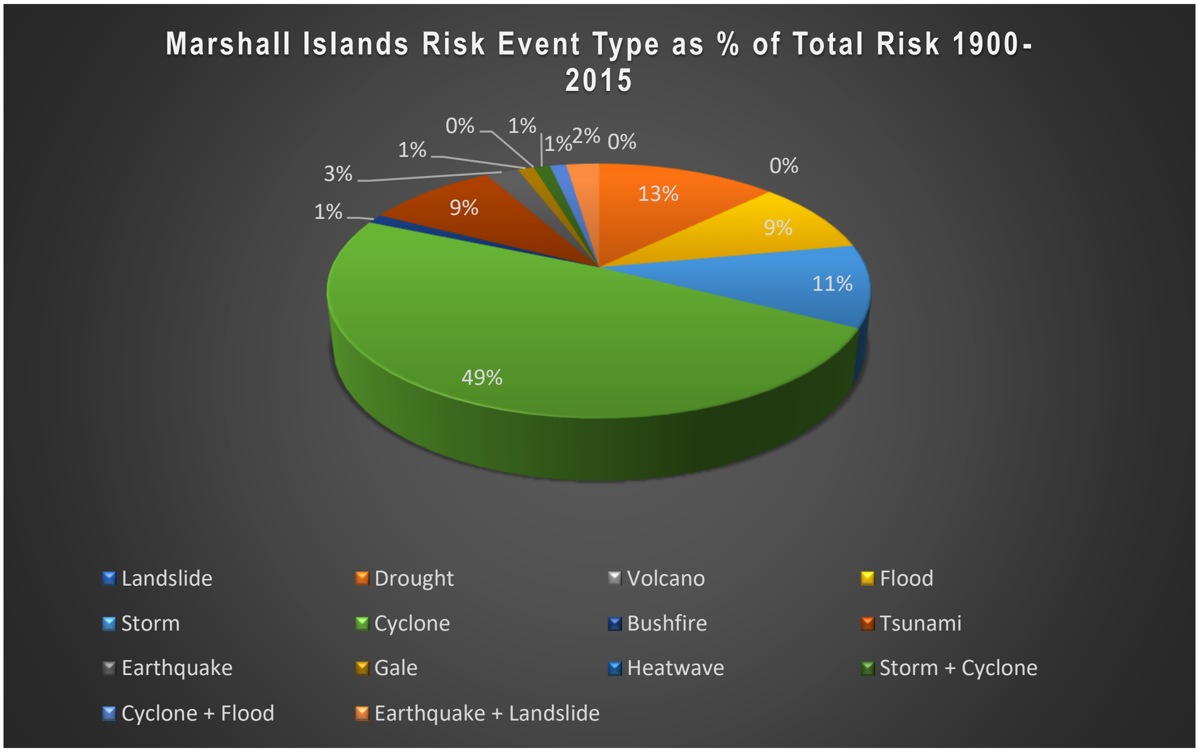
MARSHALL ISLANDS

Historical Pacific Climate Change Risk Chronology; Marshall Islands		
Year	No of Risk Events	Date (Where Information Available)
1900	F	
1901		
1902		
1903		
1904		
1905		
1906	T	01/07/1906
1907		
1908		
1909		
1910		
1911	C, D	16-17/11/1911
1912	D	
1913	D	
1914		
1915		
1916		
1917	D, H	
1918	F	
1919		
1920	C, D	
1921	C, D	
1922		
1923		
1924		
1925		
1926	C, D	
1927	D	
1928		
1929		
1930	C	
1931		
1932	C	
1933	F	
1934	C	
1935		
1936	D	
1937	D	
1938	D	
1939	C	
1940	D	
1941	D	
1942	D, H	
1943		
1944	H	
1945	C	
1946	D	

1947	C	
1948	2C	
1949		
1950	C, D	
1951	E	21/03/1951
1952	F, H	
1953	T	
1954	D	
1955	F, S	
1956	3T	
1957	C, D	07-11/03/1957; 17-18/11/1957;
1958	C	07-09/01/1958
1959		
1960		
1961		
1962		
1963	C	19-22/12/1963;
1964	C	08-10/10/1964
1965	D	
1966		
1967	C	30/08-03/09/1967;
1968		
1969	C	07-09/03/1969;
1970		
1971		
1972	C	04-07/10/1972;
1973	D	
1974		
1975		
1976		
1977	C	23-27/12/1977;
1978	C	19-20/10/1978;
1979	S, F	
1980	S, C, F, (C+F)	
1981	C	11-15/03/1981;
1982	C	25-28/03/1982;
1983	D	
1984	D	
1985		
1986	2C	11-13/08/1986; 21-23/12/1986;
1987	F, B, 2C	20-27/08/1987;
1988	S, C	8-9/01/1988;
1989		
1990	2C	05-09/11/1990; 14-24/11/1990;
1991	S, C, S+C	28/11-02/12/1991; 27/11/1991;
1992	S, C, G	07-09/01/1992; 05-07/01/1992; 05-08/08/1992;
1993		
1994	T, C, E	
1995		
1996		
1997	C	
1998	2D, C	

1999		
2000		
2001	F	
2002		
2003	C	
2004	C	
2005		
2006	B	
2007		
2008	F, S, C	
2009		
2010	C	
2011		
2012		
2013	D, S, F	
2014	F, S	
2015	D	





MARSHALL ISLANDS

Expected Probability of a Marshall Islands Climate Change Related Risk Event 1900-2015					
Total Average No of Events = 86	λ = 0.7478	**Landslides**	λ = 0	**Drought = 11**	λ = 0.0957
P(X=0)	0.4734	P(X=0)	0	P(X=0)	0.9087
P(X=1)	0.354	P(X=1)	0	P(X=1)	0.087
P(X=2)	0.1324	P(X=2)	0	P(X=2)	0.004161
P(X=3)	0.03299	P(X=3)	0	P(X=3)	0.0001327
P(X=4)	0.006188	P(X=4)	0	P(X=4)	0.000003176
P(X=5)	0.0009225	P(X=5)	0	P(X=5)	6.078E-08
Bushfire = 0	λ = 0	**Tsunami = 8**	λ =0.0696	**Earthquake = 2**	λ = 0.0174
P(X=0)	0	P(X=0)	0.9328	P(X=0)	0.9828
P(X=1)	0	P(X=1)	0.0649	P(X=1)	0.0171
P(X=2)	0	P(X=2)	0.002259	P(X=2)	0.0001488
P(X=3)	0	P(X=3)	5.241E-05	P(X=3)	1.854E-07
P(X=4)	0	P(X=4)	9.12E-07	P(X=4)	3.75E-08
P(X=5)	0	P(X=5)	1.27E-07	P(X=5)	1.3061E-11

Volcano	λ = 0	Flood = 8	λ =0.0696	Storms = 9	λ =0.0783	Cyclone = 42	λ =0.4087
P(X=0)	0	P(X=0)	0.9328	P(X=0)	0.9248	P(X=0)	0.6645
P(X=1)	0	P(X=1)	0.0649	P(X=1)	0.0723	P(X=1)	0.2716
P(X=2)	0	P(X=2)	0.002259	P(X=2)	0.002828	P(X=2)	0.0555
P(X=3)	0	P(X=3)	0.00005241	P(X=3)	7.371E-06	P(X=3)	0.007561
P(X=4)	0	P(X=4)	9.12E-07	P(X=4)	1.441E-06	P(X=4)	0.0007725
P(X=5)	0	P(X=5)	1.27E-07	P(X=5)	2.283E-08	P(X=5)	6.315E-05
Gale = 1	λ = 0.0867	**Heatwave**	λ = 0	**C+F = 1**	λ = 0.0867	**S+C = 1**	λ = 0.0867
P(X=0)	0.9913	P(X=0)	0	P(X=0)	0.9913	P(X=0)	0.9913
P(X=1)	0.0088	P(X=1)	0	P(X=1)	0.0088	P(X=1)	0.0088
P(X=2)	0.0000375	P(X=2)	0	P(X=2)	0.0000375	P(X=2)	0.0000375
P(X=3)	0.000001088	P(X=3)	0	P(X=3)	1.088E-06	P(X=3)	1.088E-06
P(X=4)	2.3664E-10	P(X=4)	0	P(X=4)	2.366E-10	P(X=4)	2.366E-10
P(X=5)	4.1775E-13	P(X=5)	0	P(X=5)	4.178E-13	P(X=5)	4.178E-13

Predicting Future Climate Change Risks Marshall Islands

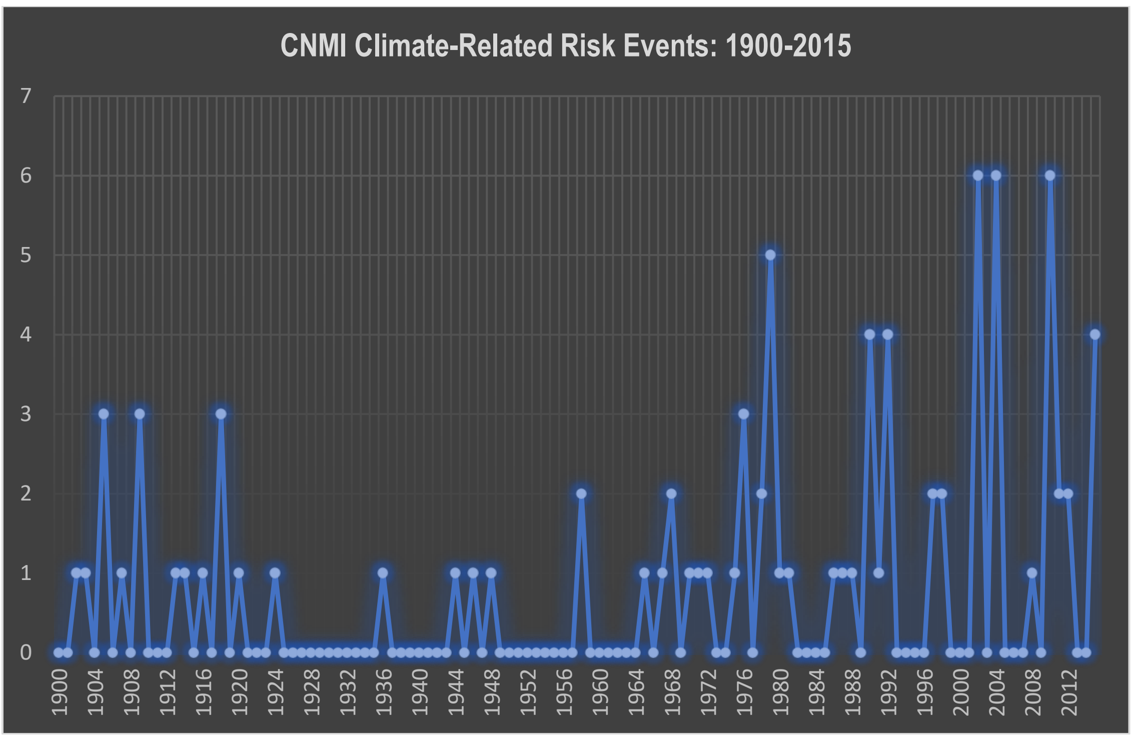
Future	**Current**	**2017**	**2018**	**2019**	**2020**		**Current**	**2017**	**2018**	**2019**	**2020**
L, B, = 0	λ = 0					**S = 9**	λ =0.0783				
P(X=0)	0	0	0	0	0	P(X=0)	0.9247	0.9167	0.9087	0.9007	0.8927
P(X=1)	0	0	0	0	0	P(X=1)	0.0724	0.0804	0.0884	0.0964	0.1044
P(X=2)	0	0	0	0	0	P(X=2)	0.002828	0.002828	0.002828	0.002828	0.002828
P(X=3)	0	0	0	0	0	P(X=3)	7.371E-06	0.000007371	0.000007371	0.000007371	0.000007371
P(X=4)	0	0	0	0	0	P(X=4)	1.441E-06	0.000001441	0.000001441	0.000001441	0.000001441
P(X=5)	0	0	0	0	0	P(X=5)	2.283E-08	2.283E-08	2.283E-08	2.283E-08	2.283E-08
Future	**Current**	**2017**	**2018**	**2019**	**2020**	**Current**	**2017**	**2018**	**2019**	**2020**	**Current**
D = 11	λ = 0.0957					**E = 2**	λ = 0.0174				
P(X=0)	0.9087	0.9007	0.8927	0.8847	0.8767	P(X=0)	0.9828	0.9748	0.9668	0.9588	0.9508
P(X=1)	0.087	0.095	0.103	0.111	0.119	P(X=1)	0.0171	0.0251	0.0331	0.0411	0.0491
P(X=2)	0.004161	0.004161	0.004161	0.004161	0.004161	P(X=2)	0.0001428	0.0001428	0.0001428	0.0001428	0.0000375
P(X=3)	0.0001327	0.0001327	0.0001327	0.0001327	0.0001327	P(X=3)	1.854E-07	1.854E-07	1.854E-07	1.854E-07	0.000001088
P(X=4)	0.000003176	0.000003176	0.000003176	0.000003176	3.176E-06	P(X=4)	3.75E-08	3.75E-08	3.75E-08	3.75E-08	2.3664E-10
P(X=5)	6.078E-08	6.078E-08	6.078E-08	6.078E-08	6.078E-08	P(X=5)	1.3061E-11	1.3061E-11	1.3061E-11	1.306E-11	4.1775E-13
Future	**Current**	**2017**	**2018**	**2019**	**2020**		**Current**	**2017**	**2018**	**2019**	**2020**
H, V = 0	λ = 0					**C = 42**	λ =0.4087				
P(X=0)	0	0	0	0	0	P(X=0)	0.6645	0.6565	0.6485	0.6405	0.6325
P(X=1)	0	0	0	0	0	P(X=1)	0.2716	0.2796	0.2876	0.2956	0.3036
P(X=2)	0	0	0	0	0	P(X=2)	0.0555	0.0555	0.0555	0.0555	0.0555
P(X=3)	0	0	0	0	0	P(X=3)	0.007561	0.007561	0.007561	0.007561	0.007561
P(X=4)	0	0	0	0	0	P(X=4)	0.0007725	0.0007725	0.0007725	0.0007725	0.0007725
P(X=5)	0	0	0	0	0	P(X=5)	0.00006315	0.00006315	0.00006315	6.315E-05	0.00006315
F, T = 8	λ =0.0696					**G = 1**	λ = 0.0867				
P(X=0)	0.9328	0.9248	0.9168	0.9088	0.9008	P(X=0)	0.9913	0.9833	0.9753	0.9673	0.9593
P(X=1)	0.0649	0.0729	0.0809	0.0889	0.0969	P(X=1)	0.0088	0.0168	0.02488	0.03288	0.04008
P(X=2)	0.002259	0.002259	0.002259	0.002259	0.002259	P(X=2)	0.0000375	0.0000375	0.0000375	0.0000375	0.0000375
P(X=3)	5.241E-05	0.00005241	0.00005241	0.00005241	5.241E-05	P(X=3)	0.000001088	1.088E-06	1.088E-06	1.088E-06	0.000001088
P(X=4)	9.12E-07	0.000000912	0.000000912	0.000000912	9.12E-07	P(X=4)	2.3664E-10	2.366E-10	2.366E-10	2.366E-10	2.3664E-10
P(X=5)	1.27E-07	0.000000127	0.000000127	0.000000127	1.27E-07	P(X=5)	4.1775E-13	4.178E-13	4.178E-13	4.178E-13	4.1775E-13

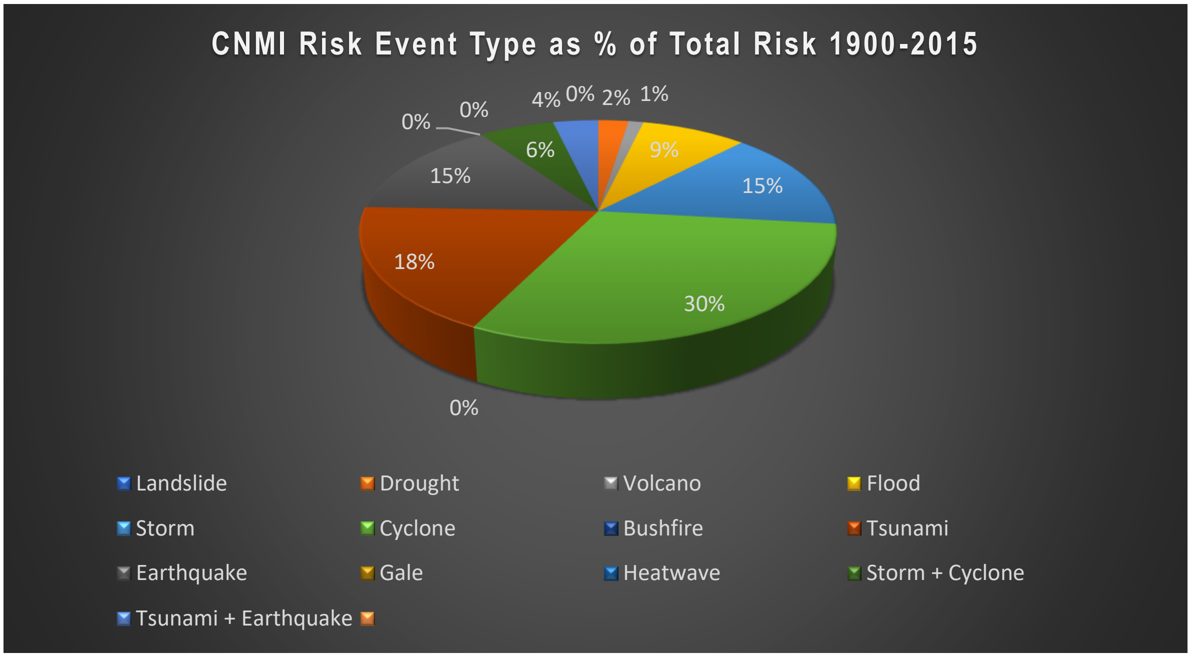
COMMONWEALTH OF THE NORTHERN MARIANAS

Historical Pacific Climate Change Risk Chronology, Northern Marianas		
Year	No of Risk Events	Date (Where Information Available)
1900		
1901		
1902	E	
1903	T	
1904		
1905	2C, F	
1906		
1907	C	
1908		
1909	T, E, T+E	
1910		
1911		
1912		
1913	C	
1914	E	
1915		
1916	T	
1917		
1918	C, F, T	
1919		
1920	T	
1921		
1922		
1923		
1924	T	
1925		
1926		
1927		
1928		
1929		
1930		
1931		
1932		
1933		
1934		
1935		
1936	E	
1937		
1938		
1939		
1940		
1941		
1942		
1943		
1944	T	
1945		
1946	T	

1947		
1948	T	
1949		
1950		
1951		
1952		
1953		
1954		
1955		
1956		
1957		
1958	S, F	
1959		
1960		
1961		
1962		
1963		
1964		
1965	S	
1966		
1967	C	
1968	S, F	
1969		
1970	E	
1971	C	
1972	C	
1973		
1974		
1975	E	
1976	2C, T	
1977		
1978	S, E	
1979	3S, C, F	
1980	C	
1981	V	
1982		
1983		
1984		
1985		
1986	C	
1987	C	
1988	C	
1989		
1990	C, T, E, T+E	05/04/1990
1991	C	
1992	C, T, E, T+E	
1993		08/08/1993
1994		
1995		
1996		
1997	2C	
1998	D, C	

1999		
2000		
2001		
2002	2S, 2C, 2(S+C)	14/08/2002; 08/12/2002;
2003		
2004	2S, 2C, 2(S+C)	26/06/2004
2005		
2006		
2007		
2008	F	
2009		
2010	3T, 3E	29/05/2010; 13/08/2010;
2011	T, F	
2012		
2013		
2014		
2015	D, S, C, S+C	01/08
2016	E	





COMMONWEALTH OF THE NORTHERN MARIANA ISLANDS

Expected Probability of a CNMI Climate Change Related Risk Event 1900-2015					
Total Average No of Events = 82	λ = 0.7130	**Landslides**	λ = 0	**Drought = 2**	λ = 0.0174
P(X=0)	0.4902	P(X=0)	0	P(X=0)	0.9828
P(X=1)	0.3495	P(X=1)	0	P(X=1)	0.0171
P(X=2)	0.1246	P(X=2)	0	P(X=2)	0.0001488
P(X=3)	0.02961	P(X=3)	0	P(X=3)	1.854E-07
P(X=4)	0.05278	P(X=4)	0	P(X=4)	3.75E-08
P(X=5)	0.0007527	P(X=5)	0	P(X=5)	1.306E-11
Bushfire = 3	λ = 0.0261	**Tsunami = 15**	λ = 0.1304	**Drought = 2**	λ = 0.0174
P(X=0)	0.9742	P(X=0)	0.8777	P(X=0)	0.9828
P(X=1)	0.0254	P(X=1)	0.1145	P(X=1)	0.0171
P(X=2)	0.003318	P(X=2)	0.007463	P(X=2)	0.0001428
P(X=3)	0.00002886	P(X=3)	0.0003244	P(X=3)	1.854E-07
P(X=4)	1.883E-07	P(X=4)	0.00001657	P(X=4)	3.75E-08
P(X=5)	9.8333E-11	P(X=5)	2.758E-07	P(X=5)	1.306E-11

Volcano = 1	$\lambda = 0.0867$	**Flood = 7**	$\lambda = 0.0609$	**Storms = 12**	$\lambda = 0.1043$	**Cyclone = 25**	$\lambda = 0.2174$
P(X=0)	0.9913	P(X=0)	0.9409	P(X=0)	0.901	P(X=0)	0.864
P(X=1)	0.0088	P(X=1)	0.0573	P(X=1)	0.0946	P(X=1)	0.1263
P(X=2)	0.0000375	P(X=2)	0.00174	P(X=2)	0.047	P(X=2)	0.001378
P(X=3)	0.000001088	P(X=3)	0.0000354	P(X=3)	0.0017	P(X=3)	0.0007489
P(X=4)	2.3664E-10	P(X=4)	5.393E-07	P(X=4)	0.00004413	P(X=4)	0.0007489
P(X=5)	4.1775E-13	P(X=5)	6.56E-08	P(X=5)	0.000009267	P(X=5)	0.000003256
Gale	$\lambda = 0$	**Heatwave = 0**	$\lambda = 0$	**S+C = 5**	$\lambda = 0.0435$	**T+E = 3**	$\lambda = 0.0261$
P(X=0)	0	P(X=0)	0	P(X=0)	0.9524	P(X=0)	0.9742
P(X=1)	0	P(X=1)	0	P(X=1)	0.0416	P(X=1)	0.0254
P(X=2)	0	P(X=2)	0	P(X=2)	0.0009059	P(X=2)	0.003318
P(X=3)	0	P(X=3)	0	P(X=3)	0.00001313	P(X=3)	2.886E-05
P(X=4)	0	P(X=4)	0	P(X=4)	1.428E-07	P(X=4)	1.883E-07

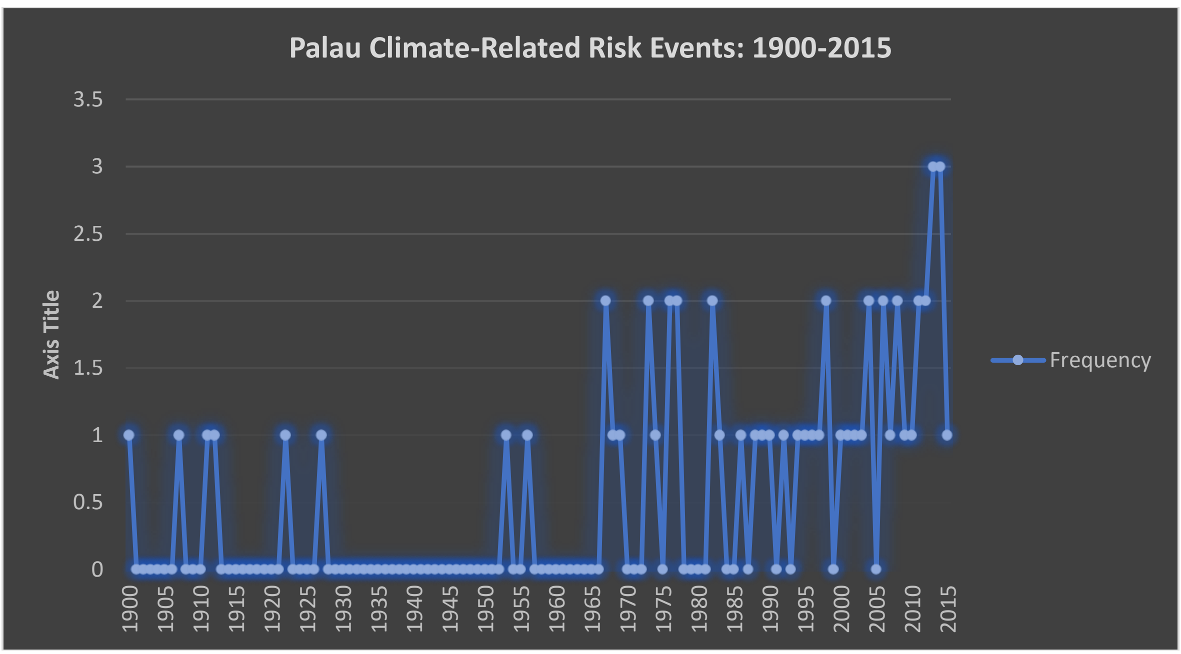
Future	Current	2017	2018	2019	2020		Current	2017	2018	2019	2020
L = 0	λ = 0					**S, E = 12**	λ =0.1043				
P(X=0)	0	0	0	0	0	P(X=0)	0.901	0.893	0.885	0.877	0.869
P(X=1)	0	0	0	0	0	P(X=1)	0.0946	0.1026	0.1106	0.1186	0.1266
P(X=2)	0	0	0	0	0	P(X=2)	0.047	0.047	0.047	0.047	0.047
P(X=3)	0	0	0	0	0	P(X=3)	0.0017	0.0017	0.0017	0.0017	0.0017
P(X=4)	0	0	0	0	0	P(X=4)	0.00004413	0.00004413	0.00004413	4.413E-05	0.00004413
P(X=5)	0	0	0	0	0	P(X=5)	0.000009267	0.000009267	0.000009267	9.267E-06	0.000009267
Future	**Current**	**2017**	**2018**	**2019**	**2020**	**Current**	**2017**	**2018**	**2019**	**2020**	**Current**
D = 2	λ = 0.0174					**V = 1**	λ = 0.0867				
P(X=0)	0.9828	0.9748	0.9668	0.9588	0.9508	P(X=0)	0.9913	0.9833	0.9753	0.9673	0.9593
P(X=1)	0.0171	0.0251	0.0331	0.0411	0.0491	P(X=1)	0.0088	0.0168	0.02488	0.03288	0.04008
P(X=2)	0.0001428	0.0001428	0.0001428	0.0001428	0.0001428	P(X=2)	0.0000375	0.0000375	0.0000375	0.0000375	0.0000375
P(X=3)	1.854E-07	1.854E-07	1.854E-07	1.854E-07	1.854E-07	P(X=3)	1.088E-06	1.088E-06	0.000001088	1.088E-06	0.000001088
P(X=4)	3.75E-08	3.75E-08	3.75E-08	3.75E-08	3.75E-08	P(X=4)	2.366E-10	2.366E-10	2.3664E-10	2.366E-10	2.3664E-10
P(X=5)	1.3061E-11	1.306E-11	1.3061E-11	1.3061E-11	1.306E-11	P(X=5)	4.178E-13	4.178E-13	4.1775E-13	4.178E-13	4.1775E-13
Future	**Current**	**2017**	**2018**	**2019**	**2020**		**Current**	**2017**	**2018**	**2019**	**2020**
H, G = 0	λ = 0					**C = 25**	λ = 0.2174				
P(X=0)	0	0	0	0	0	P(X=0)	0.864	0.856	0.848	0.84	0.832
P(X=1)	0	0	0	0	0	P(X=1)	0.1263	0.1343	0.1423	0.1503	0.1583
P(X=2)	0	0	0	0	0	P(X=2)	0.001378	0.001378	0.001378	0.001378	0.001378
P(X=3)	0	0	0	0	0	P(X=3)	0.0007489	0.0007489	0.0007489	0.0007489	0.0007489
P(X=4)	0	0	0	0	0	P(X=4)	0.0007489	0.0007489	0.0007489	0.0007489	0.0007489
P(X=5)	0	0	0	0	0	P(X=5)	0.000003256	0.000003256	0.000003256	3.256E-06	0.000003256
F = 7	λ = 0.0609					**T = 15**	λ = 0.1304				
P(X=0)	0.9409	0.9329	0.9249	0.9169	0.9089	P(X=0)	0.8777	0.8697	0.8617	0.8537	0.8457
P(X=1)	0.0573	0.0653	0.0733	0.0813	0.0893	P(X=1)	0.1145	0.1225	0.1305	0.1385	0.1465
P(X=2)	0.00174	0.00174	0.00174	0.00174	0.00174	P(X=2)	0.007463	0.007463	0.007463	0.007463	0.007463
P(X=3)	0.0000354	0.0000354	0.0000354	0.0000354	0.0000354	P(X=3)	0.0003244	0.0003244	0.0003244	0.0003244	0.0003244
P(X=4)	5.393E-07	5.393E-07	5.393E-07	5.393E-07	5.393E-07	P(X=4)	0.00001657	0.00001657	0.00001657	1.657E-05	0.00001657
P(X=5)	6.56E-08	6.56E-08	6.56E-08	6.56E-08	6.56E-08	P(X=5)	2.758E-07	2.758E-07	2.758E-07	2.758E-07	2.758E-07

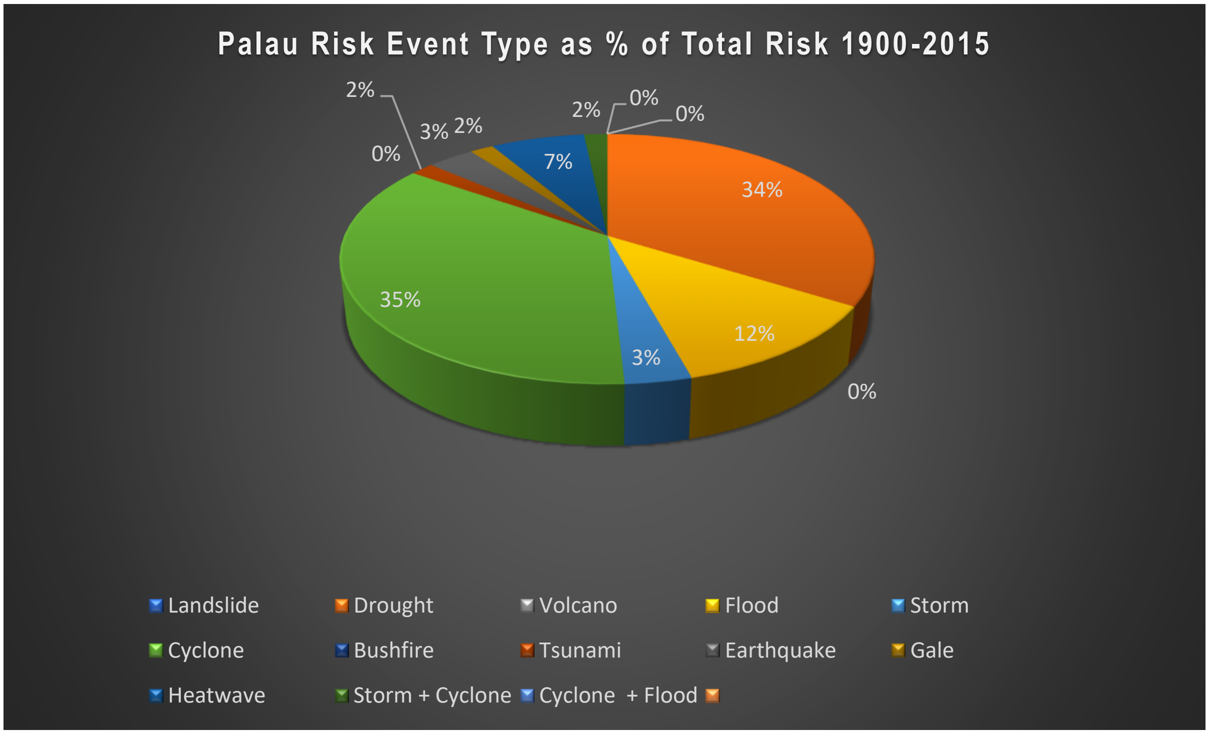
PALAU

Historical Pacific Climate Change Risk Chronology Palau		
Year	No of Risk Events	Date (Where Information Available)
1900	E	
1901		
1902		
1903		
1904		
1905		
1906		
1907	C	
1908		
1909		
1910		
1911		
1912	C	
1913		
1914		
1915		
1916		
1917		
1918		
1919		
1920		
1921		
1922	C	
1923		
1924		
1925		
1926		
1927	C	
1928		
1929		
1930		
1931		
1932		
1933		
1934		
1935		
1936		
1937		
1938		
1939		
1940		
1941		
1942		
1943		
1944		
1945		
1946		

1947		
1948		
1949		
1950		
1951		
1952		
1953	D	
1954		
1955		
1956	F	
1957		
1958		
1959		
1960		
1961		
1962		
1963		
1964		
1965		
1966		
1967	C, D	
1968	D	
1969	D	
1970		
1971		
1972		
1973	D, H	
1974	F	
1975		
1976	C, D	
1977	C, D	
1978		
1979		
1980		
1981		
1982	C, D	
1983	D	
1984		
1985		
1986	C	
1987		
1988	C	
1989	F	
1990	C	28/11/1990
1991		
1992	D	
1993	D	
1994	D	
1995	C	
1996	D	
1997	D	
1998	D, H	

1999		
2000	H	
2001	C	
2002	D	
2003	C	
2004	2C	
2005		
2006	C, D	
2007	E	
2008	F, H	
2009	T	
2010	D	
2011	F, S	
2012	2C	
2013	S, C, S+C	07/11/2013
2014	C, F, C+F	
2015	D	23/03/2015;
2016	D	





PALAU

Expected Probability of a Palau Climate Change Related Risk Event 1900-2015					
Total Average No of Events = 59	λ = 0.513	**Landslides**	λ = 0	**Drought = 20**	λ = 0.1739
P(X=0)	0.5987	P(X=0)	0	P(X=0)	0.8404
P(X=1)	0.3071	P(X=1)	0	P(X=1)	0.1461
P(X=2)	0.0788	P(X=2)	0	P(X=2)	0.01271
P(X=3)	0.01347	P(X=3)	0	P(X=3)	0.0007366
P(X=4)	0.001728	P(X=4)	0	P(X=4)	3.202E-06
P(X=5)	0.0001773	P(X=5)	0	P(X=5)	1.114E-06
Bushfire	λ = 0	**Tsunami = 1**	λ = 0.0867	**Earthquake = 2**	λ = 0.0174
P(X=0)	0	P(X=0)	0.9913	P(X=0)	0.9828
P(X=1)	0	P(X=1)	0.0088	P(X=1)	0.0171
P(X=2)	0	P(X=2)	0.0000375	P(X=2)	0.0001488
P(X=3)	0	P(X=3)	1.088E-06	P(X=3)	1.854E-07
P(X=4)	0	P(X=4)	2.366E-10	P(X=4)	3.75E-08
P(X=5)	0	P(X=5)	4.178E-13	P(X=5)	1.306E-11

Volcano	λ = 0	**Flood = 7**	λ = 0.0609	**Storms = 2**	λ = 0.0174	**Cyclone = 21**	λ = 0.1826
P(X=0)	0	P(X=0)	0.9409	P(X=0)	0.9828	P(X=0)	0.8321
P(X=1)	0	P(X=1)	0.0573	P(X=1)	0.0171	P(X=1)	0.1521
P(X=2)	0	P(X=2)	0.00174	P(X=2)	0.0001428	P(X=2)	0.01389
P(X=3)	0	P(X=3)	0.0000354	P(X=3)	1.854E-07	P(X=3)	0.0008454
P(X=4)	0	P(X=4)	5.393E-07	P(X=4)	3.75E-08	P(X=4)	0.0003859
P(X=5)	0	P(X=5)	6.56E-08	P(X=5)	1.306E-11	P(X=5)	8.409E-05
Gale = 1	λ = 0.0867	**Heatwave = 4**	λ =0.0348	**S+C = 1**	λ = 0.0867	**T+E = 1**	λ = 0.0867
P(X=0)	0.9913	P(X=0)	0.9658	P(X=0)	0.9913	P(X=0)	0.9913
P(X=1)	0.0088	P(X=1)	0.0336	P(X=1)	0.0088	P(X=1)	0.0088
P(X=2)	0.0000375	P(X=2)	0.0005846	P(X=2)	0.0000375	P(X=2)	0.0000375
P(X=3)	0.000001088	P(X=3)	7.24E-07	P(X=3)	1.088E-06	P(X=3)	1.088E-06
P(X=4)	2.3664E-10	P(X=4)	5.901E-09	P(X=4)	2.366E-10	P(X=4)	2.366E-10
P(X=5)	4.1775E-13	P(X=5)	4.1077E-10	P(X=5)	4.178E-13	P(X=5)	4.178E-13

Predicting Future Climate Change Risks Palau

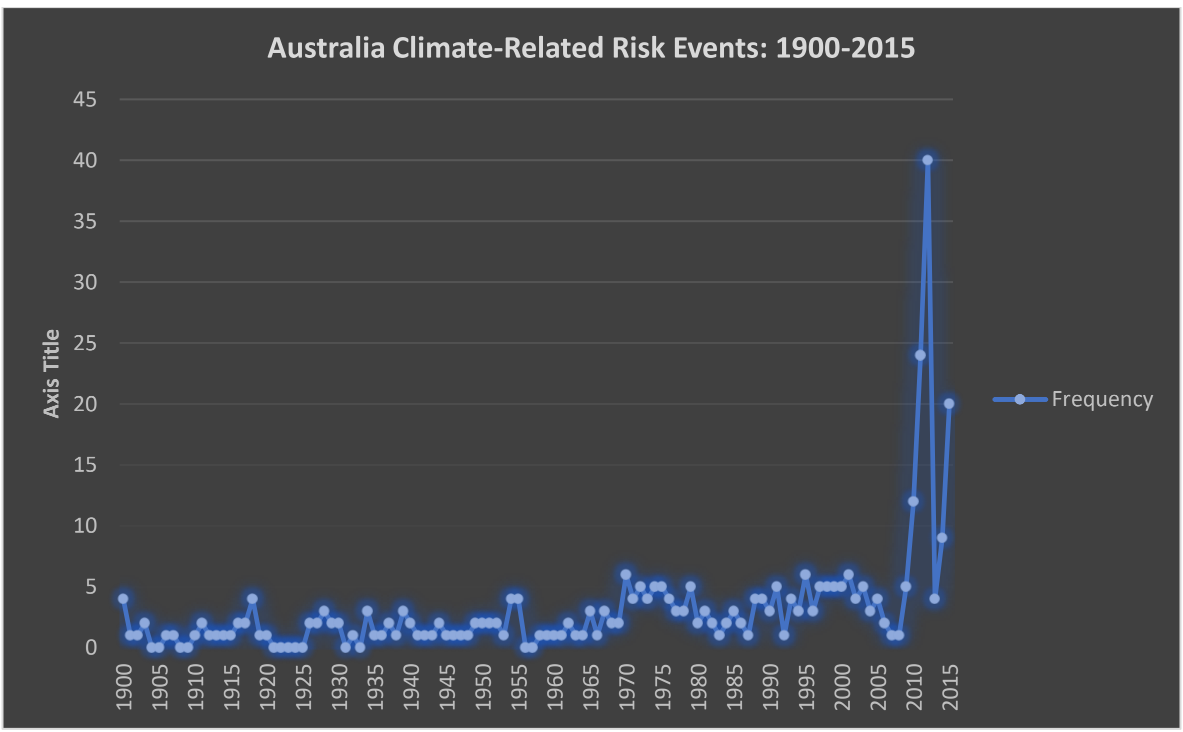
Future	**Current**	**2017**	**2018**	**2019**	**2020**		**Current**	**2017**	**2018**	**2019**	**2020**
L = 0	λ = 0					**S = 2**	λ = 0.0174				
P(X=0)	0	0	0	0	0	P(X=0)	0.9828	0.9748	0.9668	0.9588	0.9508
P(X=1)	0	0	0	0	0	P(X=1)	0.0171	0.0251	0.0331	0.0411	0.0491
P(X=2)	0	0	0	0	0	P(X=2)	0.0001428	0.0001428	0.0001428	0.0001428	0.0001428
P(X=3)	0	0	0	0	0	P(X=3)	1.854E-07	1.854E-07	1.854E-07	1.854E-07	1.854E-07
P(X=4)	0	0	0	0	0	P(X=4)	3.75E-08	3.75E-08	3.75E-08	3.75E-08	3.75E-08
P(X=5)	0	0	0	0	0	P(X=5)	1.3061E-11	1.3061E-11	1.306E-11	1.3061E-11	1.3061E-11
Future	**Current**	**2017**	**2018**	**2019**	**2020**	**Current**	**2017**	**2018**	**2019**	**2020**	**Current**
D = 20	λ = 0.1739				**Drought = 20**	0.01271	0.01271	0.01271	0.01271	0.01271	0.01271
P(X=0)	0.8404	0.8324	0.8244	0.8164	0.8158	0.0007366	0.0007366	0.0007366	0.0007366	0.0007366	0.0007366
P(X=1)	0.1461	0.1541	0.1621	0.1701	0.1781	0.000003202	0.000003202	0.000003202	0.000003202	0.000003202	0.000003202
P(X=2)	0.01271	0.01271	0.01271	0.01271	0.01271	0.000001114	0.000001114	0.000001114	0.000001114	0.000001114	0.000001114
P(X=3)	0.0007366	0.0007366	0.0007366	0.0007366	0.0007366	0.01271	0.01271	0.01271	0.01271	0.01271	0.01271
P(X=4)	0.000003202	0.000003202	0.000003202	0.000003202	0.000003202	0.0007366	0.0007366	0.0007366	0.0007366	0.0007366	0.0007366
P(X=5)	0.000001114	0.000001114	0.000001114	0.000001114	0.000001114	0.000003202	0.000003202	0.000003202	0.000003202	0.000003202	0.000003202
Future	**Current**	**2017**	**2018**	**2019**	**2020**		**Current**	**2017**	**2018**	**2019**	**2020**
H = 4	λ =0.0348					**C = 21**	λ = 0.1826				
P(X=0)	0.9658	0.9578	0.9498	0.9418	0.9338	P(X=0)	0.8321	0.8241	0.8161	0.8081	0.8001
P(X=1)	0.0336	0.0416	0.0496	0.0576	0.0656	P(X=1)	0.1521	0.1601	0.1681	0.1761	0.1841
P(X=2)	0.0005846	0.0005846	0.0005846	0.0005846	0.0005846	P(X=2)	0.01389	0.01389	0.01389	0.01389	0.01389
P(X=3)	7.24E-07	0.000000724	0.000000724	0.000000724	7.24E-07	P(X=3)	0.0008454	0.0008454	0.0008454	0.0008454	0.0008454
P(X=4)	5.901E-09	5.901E-09	5.901E-09	5.901E-09	5.901E-09	P(X=4)	0.0003859	0.0003859	0.0003859	0.0003859	0.0003859
P(X=5)	4.108E-10	4.1077E-10	4.1077E-10	4.1077E-10	4.108E-10	P(X=5)	0.00008409	0.00008409	0.00008409	0.00008409	0.00008409
Flood = 7	λ = 0.0609					**G, T = 1**	λ = 0.0867				
P(X=0)	0.9409	0.9329	0.9249	0.9169	0.9089	P(X=0)	0.9913	0.9833	0.9753	0.9673	0.9593
P(X=1)	0.0573	0.0653	0.0733	0.0813	0.0893	P(X=1)	0.0088	0.0168	0.02488	0.03288	0.04008
P(X=2)	0.00174	0.00174	0.00174	0.00174	0.00174	P(X=2)	0.0000375	3.8E-05	0.0000375	0.0000375	0.0000375
P(X=3)	0.0000354	0.0000354	0.0000354	0.0000354	0.0000354	P(X=3)	0.000001088	1.1E-06	0.000001088	1.088E-06	0.000001088
P(X=4)	5.393E-07	5.393E-07	5.393E-07	5.393E-07	5.393E-07	P(X=4)	2.3664E-10	2.4E-10	2.3664E-10	2.366E-10	2.3664E-10
P(X=5)	6.56E-08	6.56E-08	6.56E-08	6.56E-08	6.56E-08	P(X=5)	4.1775E-13	4.2E-13	4.1775E-13	4.178E-13	4.1775E-13

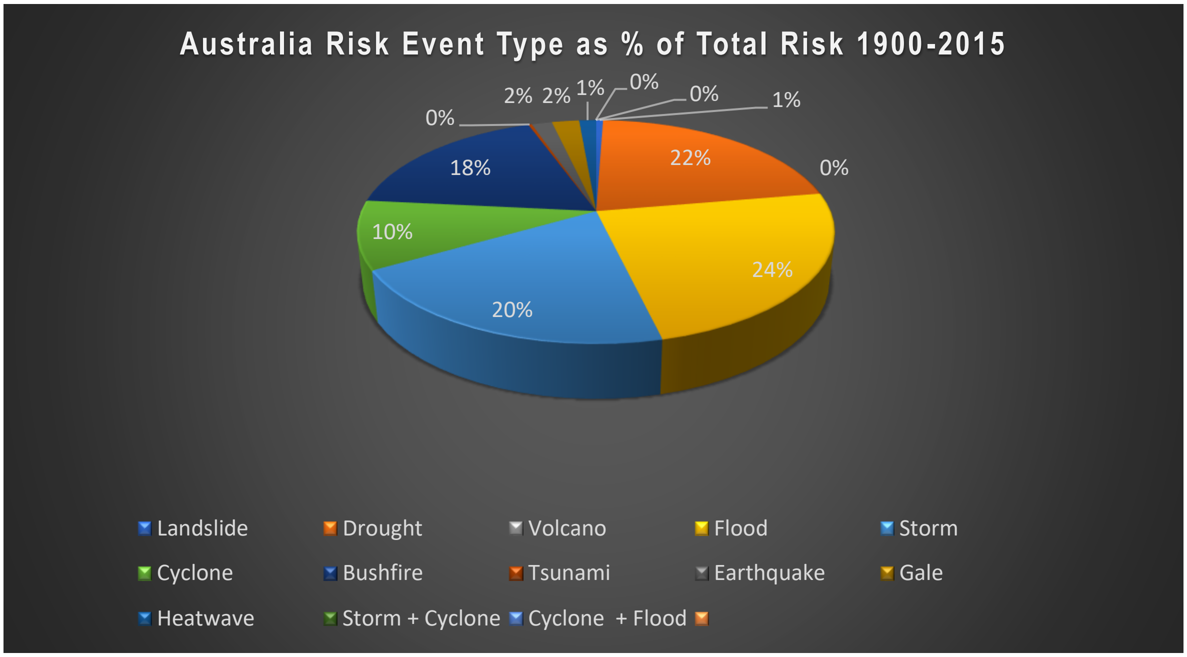
AUSTRALIA

Historical Pacific Climate Change Risk Chronology Australia		
Year	**No of Risk Events**	
1900	E, D, F, T	
1901	D	
1902	D	
1903	D, C	
1904		
1905		
1906	B	
1907	C	
1908		
1909		
1910	C	
1911	D, C	
1912	D	
1913	D	
1914	D	
1915	D	
1916	D, F	
1917	B, F	
1918	D, B, 2C	
1919	D	
1920	D	
1921		
1922		
1923		
1924		
1925		
1926	D, B	
1927	D, F	
1928	D, F, L	
1929	D, F	
1930	D, F	
1931		
1932	B	
1933		
1934	F, D, S	
1935	D	
1936	D	
1937	D, S	
1938	D	
1939	D, B, H	
1940	D, F	
1941	D	
1942	D	
1943	D	
1944	D, B	
1945	D	
1946	D	

1947	D	
1948	D	
1949	D, C	
1950	D, F	
1951	D, B	
1952	D, F	
1953	D	
1954	D, B, C, E	
1955	C, 2F, B,	February 1955-F;
1956		
1957		
1958	D	
1959	D	
1960	D	07/02/1967-B;
1961	D	
1962	D, B	
1963	D	
1964	D	
1965	D, 2B	
1966	D	
1967	C, D, B	
1968	E, D	14/10/1968-E;
1969	C, B	
1970	3S, C, F, G	January-S 21-30/12/1970;
1971	C, F, 2G	05-16/01/1991-C; 12-20/04/1971; 08-12/05/1971-G
1972	3C, D	
1973	3C, D, G,	05/03-02/04/1973; 16-19/12/1973; 23-25/01/1973-G
1974	2S, G, D, C	
1975	2S, C, D, F	11-21/01/1975-C; 31/1-01/02/1975-S;
1976	C, S, D, G	
1977	F, S, B	
1978	D, F, S	
1979	2C, E, S, B	04-12/01/1979-C;
1980	D, B	
1981	D, F, S	
1982	S, D	
1983	B	
1984	F, B	
1985	F, S, B,	
1986	F, S	
1987	S	
1988	S, F, G, E	01-04/04/1988-S; 22/01/1988-E;
1989	S, C, F, E,	23/05/1989-E;
1990	S, 2F	31/01-08/02/1990;
1991	S, C, D, B, F	24/02-09/03/1991-C;
1992	D	
1993	S, F, H, D	
1994	S, F, G	
1995	S, C, F, G, H, D	01/02/04//1995-S; 07-18/03/1995-C; 16-18/02/1995 –G;
1996	G, C, D	23/24/02/1996-G; 04-33/03/1996-C;
1997	S, L, F, B, D	
1998	C, 2S, F, D	01/01-15/02/1998

1999	3S, B, D	10-12/02/1999-S;
2000	S, C, F, B, D	
2001	F, 3S, B, D	05-11/04/2011-S;
2002	S, B, 2D	
2003	S, 2F, B, D	
2004	S, F, D	
2005	S, F, B, D	
2006	C, D	
2007	D	
2008	D	
2009	S, F, B, H, D	
2010	10S, F, D	
2011	6S, 15F, 4B, C	C-26/01-07/02/2011;
2012	5S, 7F, 25B,	
2013	S, B, D, F	
2014	S, C, 4F, D, H, B	
2015	3S, 3C, 11F, 3B	
2016	8S,11F, B	





AUSTRALIA

Expected Probability of an Australia Climate Change Related Risk Event 1900-2015					
Total Average No of Events = 363	λ = 3.1565	**Landslides = 2**	λ = 0.0174	**Drought = 79**	λ =0.687
P(X=0)	0.04257	P(X=0)	0.9828	P(X=0)	0.5031
P(X=1)	0.1344	P(X=1)	0.0171	P(X=1)	0.3456
P(X=2)	0.2121	P(X=2)	0.0001488	P(X=2)	0.1127
P(X=3)	0.2232	P(X=3)	1.854E-07	P(X=3)	0.0272
P(X=4)	0.1761	P(X=4)	3.75E-08	P(X=4)	0.004669
P(X=5)	0.1112	P(X=5)	1.306E-11	P(X=5)	0.0006416
Bushfire = 65	λ = 0.5652	**Tsunami = 1**	λ = 0.0867	**Earthquake = 6**	λ = 0.05222
P(X=0)	0.5682	P(X=0)	0.9913	P(X=0)	0.9491
P(X=1)	0.3212	P(X=1)	0.0088	P(X=1)	0.0495
P(X=2)	0.0908	P(X=2)	0.0000375	P(X=2)	0.001293
P(X=3)	0.0171	P(X=3)	1.088E-06	P(X=3)	0.0000225
P(X=4)	0.002416	P(X=4)	2.366E-10	P(X=4)	2.936E-07
P(X=5)	0.0002731	P(X=5)	4.178E-13	P(X=5)	1.91E-10

Volcano = 0	λ = 0	**Flood = 87**	λ = 0.7565	**Storms = 74**	λ = 0.6435	**Heatwave = 5**	λ =0.0435
P(X=0)	0	P(X=0)	0.4693	P(X=0)	0.5255	P(X=0)	0.9524
P(X=1)	0	P(X=1)	0.355	P(X=1)	0.3381	P(X=1)	0.0416
P(X=2)	0	P(X=2)	0.1343	P(X=2)	0.1088	P(X=2)	0.0009059
P(X=3)	0	P(X=3)	0.03386	P(X=3)	0.0233	P(X=3)	0.00001313
P(X=4)	0	P(X=4)	0.06404	P(X=4)	0.003754	P(X=4)	1.428E-07
P(X=5)	0	P(X=5)	0.00369	P(X=5)	0.0004832	P(X=5)	1.24E-09
Gale = 8	λ =0.0696	**Heatwave = 1**	λ = 0.0867	**S+C = 5**	λ =0.0435	**T+E = 0**	λ = 0
P(X=0)	0.9328	P(X=0)	0.9913	P(X=0)	0.9524	P(X=0)	0
P(X=1)	0.0649	P(X=1)	0.0088	P(X=1)	0.0416	P(X=1)	0
P(X=2)	0.002259	P(X=2)	0.0000375	P(X=2)	0.0009059	P(X=2)	0
P(X=3)	0.00005241	P(X=3)	0.000001088	P(X=3)	0.00001313	P(X=3)	0
P(X=4)	0.000000912	P(X=4)	2.3664E-10	P(X=4)	1.428E-07	P(X=4)	0

Predicting Future Climate Change Risks Australia

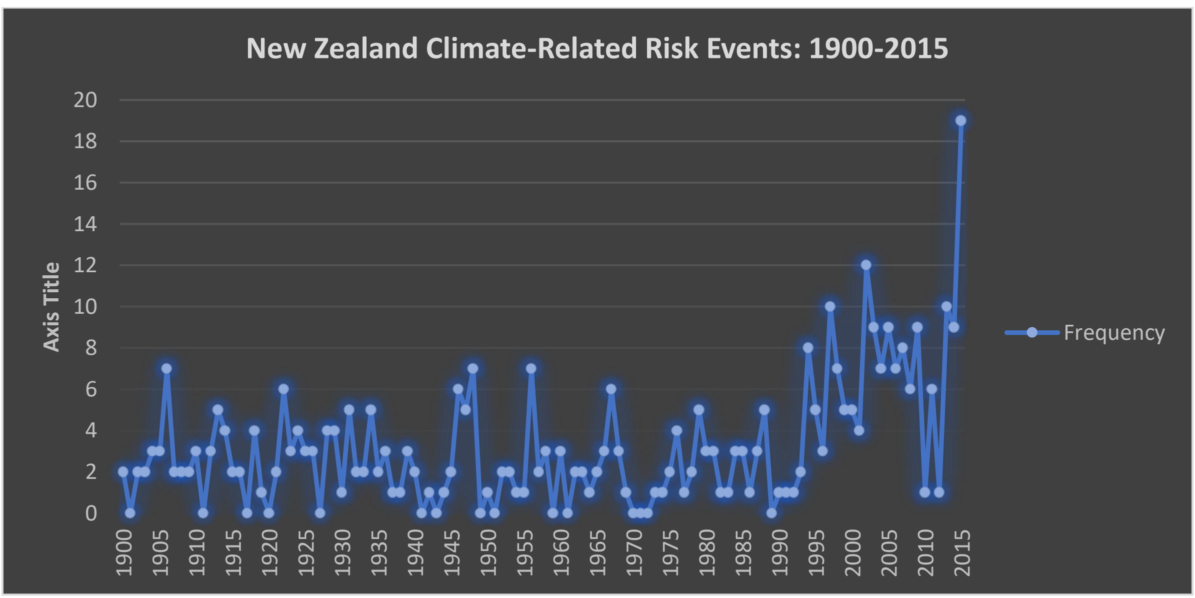
Future	**Current**	**2017**	**2018**	**2019**	**2020**		**Current**	**2017**	**2018**	**2019**	**2020**
L = 2	λ = 0.0174					**S = 74**	λ = 0.6435				**Storms = 74**
P(X=0)	0.9828	0.9748	0.9668	0.9588	0.9508	P(X=0)	0.5255	0.5175	0.5095	0.5015	P(X=0)
P(X=1)	0.0171	0.0251	0.0331	0.0411	0.0491	P(X=1)	0.3381	0.3461	0.3541	0.3621	P(X=1)
P(X=2)	0.0001428	0.0001428	0.0001428	0.0001428	0.0001428	P(X=2)	0.1088	0.1088	0.1088	0.1088	P(X=2)
P(X=3)	1.854E-07	1.854E-07	1.854E-07	1.854E-07	1.854E-07	P(X=3)	0.0233	0.0233	0.0233	0.0233	P(X=3)
P(X=4)	3.75E-08	3.75E-08	3.75E-08	3.75E-08	3.75E-08	P(X=4)	0.003754	0.003754	0.003754	0.003754	P(X=4)
P(X=5)	1.306E-11	1.3061E-11	1.3061E-11	1.3061E-11	1.3061E-11	P(X=5)	0.0004832	0.0004832	0.0004832	0.0004832	P(X=5)
Future	**Current**	**2017**	**2018**	**2019**	**2020**	**Current**	**2017**	**2018**	**2019**	**2020**	**Current**
D= 79	λ =0.687					**V = 0**	λ = 0				
P(X=0)	0.5031					P(X=0)	0	0	0	0	0
P(X=1)	0.3456					P(X=1)	0	0	0	0	0
P(X=2)	0.1127	0.1127	0.1127	0.1127	0.1127	P(X=2)	0	0	0	0	0
P(X=3)	0.0272	0.0272	0.0272	0.0272	0.0272	P(X=3)	0	0	0	0	0
P(X=4)	0.004669	0.004669	0.004669	0.004669	0.004669	P(X=4)	0	0	0	0	0
P(X=5)	0.0006416	0.0006416	0.0006416	0.0006416	0.0006416	P(X=5)	0	0	0	0	0
Future	**Current**	**2017**	**2018**	**2019**	**2020**		**Current**	**2017**	**2018**	**2019**	**2020**
E = 6	λ = 0.05222					**C = 36**	λ = 0.313				
P(X=0)	0.9491	0.9411	0.9331	0.9251	0.9171	P(X=0)	0.7312	0.7232	0.7152	0.7072	0.6992
P(X=1)	0.0495	0.0575	0.0655	0.0735	0.0815	P(X=1)	0.2289	0.2369	0.2449	0.2529	0.2609
P(X=2)	0.001293	0.001293	0.001293	0.001293	0.001293	P(X=2)	0.0358	0.0358	0.0358	0.0358	0.0358
P(X=3)	0.0000225	0.0000225	0.0000225	0.0000225	0.0000225	P(X=3)	0.003737	0.003737	0.003737	0.003737	0.003737
P(X=4)	2.936E-07	2.936E-07	2.936E-07	2.936E-07	2.936E-07	P(X=4)	0.0002924	0.0002924	0.0002924	0.0002924	0.0002924
P(X=5)	1.91E-10	1.91E-10	1.91E-10	1.91E-10	1.91E-10	P(X=5)	0.00001831	0.00001831	0.00001831	0.00001831	0.00001831
F = 87	λ = 0.7565					**T = 1**	λ = 0.0867				
P(X=0)	0.4693	0.4613	0.4533	0.4453	0.4373	P(X=0)	0.9913	0.9833	0.9753	0.9673	0.9593
P(X=1)	0.355	0.363	0.371	0.379	0.387	P(X=1)	0.0088	0.0168	0.02488	0.03288	0.04008
P(X=2)	0.1343	0.1343	0.1343	0.1343	0.1343	P(X=2)	0.0000375	0.0000375	0.0000375	0.0000375	0.0000375
P(X=3)	0.03386	0.03386	0.03386	0.03386	0.03386	P(X=3)	1.088E-06	0.000001088	0.000001088	0.000001088	0.000001088
P(X=4)	0.06404	0.06404	0.06404	0.06404	0.06404	P(X=4)	2.366E-10	2.3664E-10	2.3664E-10	2.3664E-10	2.3664E-10
P(X=5)	0.00369	0.00369	0.00369	0.00369	0.00369	P(X=5)	4.178E-13	4.1775E-13	4.1775E-13	4.1775E-13	4.1775E-13

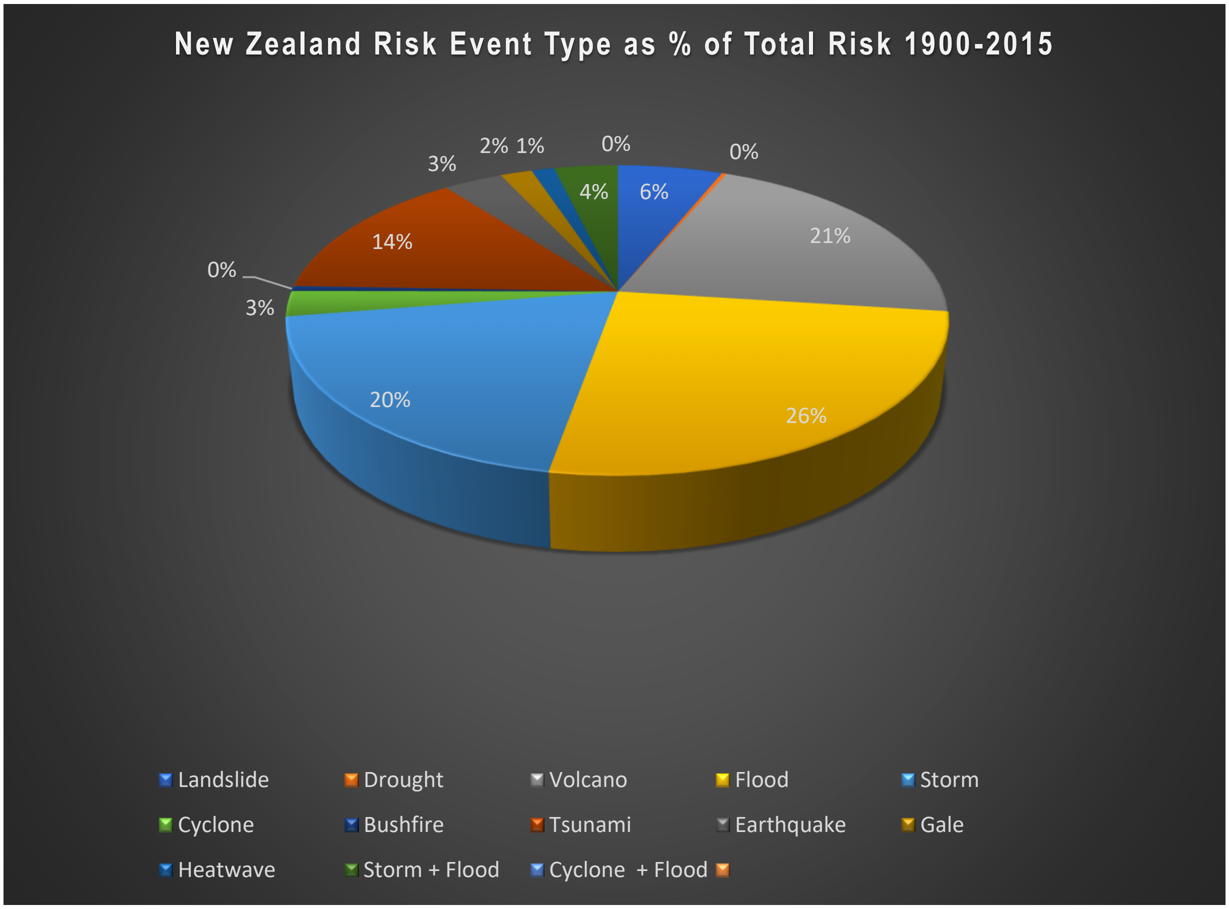
NEW ZEALAND

Historical Pacific Climate Change Risk Chronology, New Zealand		
Year	**No of Risk Events**	
1900	V, S	
1901		
1902		
1903	V, F	
1904	T, V, F	
1905	3V	
1906	2T, 3V, F, G	
1907	2V	
1908	V, S	
1909	2V	
1910	3V	
1911		
1912	V, 2S	
1913	3V, 2T	
1914	L, T, 2V	06/20/1914-T
1915	2V	
1916	2V	
1917		
1918	2V, G, B	
1919	S	
1920		
1921	F, V	
1922	5T, V	25/12/1922-T;
1923	S, F, T	
1924	T, S, V, L	
1925	2V, F	
1926	2V, S	
1927		
1928	3V, F	
1929	F, E, T, G	16/06/1929
1930	V	
1931	S, E, 2T, V	02/02/1931; 13/02/1931;
1932	S, T	15/09/1932
1933	V, F	
1934	S, 4V	
1935	2F	
1936	C, F, T	19/02/1936
1937	V	
1938	F	
1939	F, T, V	05/03/1939
1940	2V	
1941		
1942	V	
1943		
1944	S	
1945	V, F	
1946	5T, V	

1947	4T, V	25/03/1947-T;
1948	3T, 3V, F	09/02/1948-V; 01/05/1948-V;
1949		
1950	T	14/03/1950
1951		
1952	2T	
1953	2S	24-26/01/1953; 05-07/03/1953;
1954	V	13/05/1954
1955	V	16/01/1955;
1956	2S, 2F, T, 2V	
1957	T, V	11/12/1957
1958	3V	05/11/1958
1959		
1960	5T	23/05/1960;
1961		
1962	2V	24/05/1962; 15/12/1962;
1963	S, F	
1964	T	
1965	2F	
1966	S, F, V	13/11/1966-V
1967	C, S, E, 3V	22/07/1967;
1968	E, C, S	23/05/1968-E'
1969	V	22/06/1969
1970		
1971		
1972		
1973	V	15/10/1973
1974	V	08/09/1974
1975	S, V	4-12/03/1975-S; 24/04/1975-V;
1976	E, 2F, T	28/09/1976-T
1977	F	
1978	E, F	31/01-12/02/1978-F
1979	S, C, L, T, F	12/10/1979-T
1980	2F, G	
1981	2F, T	25/05/1981-T
1982	T	
1983	F	
1984	3F	
1985	3F	
1986	F	
1987	F, E, B	20/05/1987-E
1988	3F, S, C	
1989		
1990	F	
1991	F	15-21/11/1991;
1992	S	14-23/02/1992
1993	F, T	16806/1993-T;
1994	2S, 2F, 2(F+S), 2T	
1995	C, 4F,	
1996	S, C, V	16/06/1996-V
1997	5F, 3S, G, C	07-07/10/1997; 03-10/01/1997-C
1998	1(S+F), 4S, 1F, T	

1999	S, 4F	18/04/1999; 12/11/1999-F;
2000	3F, S, H	12/10/2000-F
2001	H, F, 2S	
2002	5S, 4F, 2(S+F), L	10-14/01/2002-F;
2003	3S, 2F, T, 3L	21/08/2003 -T; 31/03/2003-F;
2004	4S, 2F, L	11/02/2004-L;
2005	2S, 3F, 4L	01/05/2005; 18/05/2005;
2006	3S, 2F, S+F, L	15/12/2007-L
2007	G, 3S, 2F, 2S, E, F, L	23/24/10/2007-G; 30/09/2007-E; 29/07-01/08/2007 –F/L/S;
2008	2S, E, F, 2L	26/08/2008-F; 15/12/2008-L;
2009	2S, B, E, F, H,	15/07/2009 –E;
2010	E, 2L	10/09/2010-L; 01/05/2010;
2011	S, 3F, S+F, E, L	05-15/01/2011-S;30/07-1/08/2015 S+F; 06/07/2011-E; 10/06/2011-L
2012	S,	
2013	D, 3S, 2E, (S+F), 2T, F	15-17/06/2013 –S; 21/07/2013-T/E; 16/08/2013-T
2014	3S, F, S+F, C, H, 2L	07-14/03/2014-C
2015	5(S+F), 5S, 5 F, C, H, 2L	21/05/2015-F; 29/06/2015-F
2016	4F, G, 2V	01/04/2016-V; 13/09/2016 -V;





NEW ZEALAND

Expected Probability of a New Zealand Climate Change Related Risk Event 1900-2015					
Total Average No of Events = 377	λ = 3.2783	**Landslides = 23**	λ =0.2	**Drought = 1**	λ = 0.0867
P(X=0)	0.03769	P(X=0)	0.8187	P(X=0)	0.9913
P(X=1)	0.1236	P(X=1)	0.1637	P(X=1)	0.0088
P(X=2)	0.2025	P(X=2)	0.01637	P(X=2)	0.0000375
P(X=3)	0.2213	P(X=3)	0.001092	P(X=3)	0.000001088
P(X=4)	0.1814	P(X=4)	0.00000545	P(X=4)	2.3664E-10
P(X=5)	0.1189	P(X=5)	0.00002183	P(X=5)	4.1775E-13
Bushfire = 2	λ = 0.0174	**Tsunami = 53**	λ = 0.4609	**Earthquake = 96**	λ =0.8348
P(X=0)	0.9828	P(X=0)	0.6307	P(X=0)	0.4334
P(X=1)	0.0171	P(X=1)	0.2906	P(X=1)	0.3623
P(X=2)	0.0001488	P(X=2)	0.06699	P(X=2)	0.1512
P(X=3)	1.854E-07	P(X=3)	0.1029	P(X=3)	0.04208
P(X=4)	3.75E-08	P(X=4)	0.001186	P(X=4)	0.008782
P(X=5)	1.306E-11	P(X=5)	0.0001093	P(X=5)	0.001466

Volcano = 78	λ = 0.6783	Flood = 97	λ = 0.7913	Storms = 74	λ = 0.6435	Cyclone = 10	λ = 0.087
P(X=0)	0.5075	P(X=0)	0.4533	P(X=0)	λ = 0.6435	P(X=0)	0.9187
P(X=1)	0.3442	P(X=1)	0.3587	P(X=1)	0.5255	P(X=1)	0.07915
P(X=2)	0.1167	P(X=2)	0.1419	P(X=2)	0.3381	P(X=2)	0.003469
P(X=3)	0.0264	P(X=3)	0.03743	P(X=3)	0.1088	P(X=3)	0.000996
P(X=4)	0.004476	P(X=4)	0.07405	P(X=4)	0.0233	P(X=4)	0.00002159
P(X=5)	0.006872	P(X=5)	0.001172	P(X=5)	0.003754	P(X=5)	3.743E-07
Gale = 3	λ = 0.0261	**Heatwave = 0**	λ = 0	**T+E = 2**	λ = 0.0174	**S+C = 2**	λ = 0.0174
P(X=0)	0.9742	P(X=0)	0	P(X=0)	0.9828	P(X=0)	0.9828
P(X=1)	0.0254	P(X=1)	0	P(X=1)	0.0171	P(X=1)	0.0171
P(X=2)	0.003318	P(X=2)	0	P(X=2)	0.0001488	P(X=2)	0.0001488
P(X=3)	0.00002886	P(X=3)	0	P(X=3)	1.854E-07	P(X=3)	1.854E-07
P(X=4)	1.883E-07	P(X=4)	0	P(X=4)	3.75E-08	P(X=4)	3.75E-08
P(X=5)	9.8333E-11	P(X=5)	0	P(X=5)	1.3061E-11	P(X=5)	1.3061E-11

Predicting Future Climate Change Risks New Zealand

Future	**Current**	**2017**	**2018**	**2019**	**2020**		**Current**	**2017**	**2018**	**2019**	**2020**
H = 0	λ = 0					**S = 74**	λ = 0.6435				
P(X=0)	0	0	0	0	0	P(X=0)	0.5255	0.5175	0.5095	0.5015	0.4935
P(X=1)	0	0	0	0	0	P(X=1)	0.3381	0.3461	0.3541	0.3621	0.3701
P(X=2)	0	0	0	0	0	P(X=2)	0.1088	0.1088	0.1088	0.1088	0.1088
P(X=3)	0	0	0	0	0	P(X=3)	0.0233	0.0233	0.0233	0.0233	0.0233
P(X=4)	0	0	0	0	0	P(X=4)	0.003754	0.003754	0.003754	0.003754	0.003754
P(X=5)	0	0	0	0	0	P(X=5)	0.0004832	0.0004832	0.0004832	0.0004832	0.0004832
Future	**Current**	**2017**	**2018**	**2019**	**2020**	**Current**	**2017**	**2018**	**2019**	**2020**	**Current**
D = 1	λ = 0.0867					**V = 78**	λ = 0.6783				
P(X=0)	0.9913	0.9833	0.9753	0.9673	0.9593	P(X=0)	0.5075	0.4995	0.4915	0.4835	0.4755
P(X=1)	0.0088	0.0168	0.02488	0.03288	0.04008	P(X=1)	0.3442	0.3522	0.3602	0.3682	0.3762
P(X=2)	0.0000375	0.0000375	0.0000375	0.0000375	0.0000375	P(X=2)	0.1167	0.1167	0.1167	0.1167	0.1167
P(X=3)	0.000001088	0.000001088	1.088E-06	0.000001088	0.000001088	P(X=3)	0.0264	0.0264	0.0264	0.0264	0.0264
P(X=4)	2.3664E-10	2.3664E-10	2.366E-10	2.3664E-10	2.3664E-10	P(X=4)	0.004476	0.004476	0.004476	0.004476	0.004476
P(X=5)	4.1775E-13	4.1775E-13	4.178E-13	4.1775E-13	4.1775E-13	P(X=5)	0.006872	0.006872	0.006872	0.006872	0.006872
Future	**Current**	**2017**	**2018**	**2019**	**2020**		**Current**	**2017**	**2018**	**2019**	**2020**
L = 23	λ =0.2					**C = 10**	λ = 0.087				
P(X=0)	0.8187	0.8107	0.8027	0.7947	0.7867	P(X=0)	0.9187	0.9107	0.9027	0.8947	0.8867
P(X=1)	0.1637	0.1717	0.1797	0.1877	0.1957	P(X=1)	0.07915	0.08715	0.09515	0.10315	0.11115
P(X=2)	0.01637	0.01637	0.01637	0.01637	0.01637	P(X=2)	0.003469	0.003469	0.003469	0.003469	0.003469
P(X=3)	0.001092	0.001092	0.001092	0.001092	0.001092	P(X=3)	0.000996	0.000996	0.000996	0.000996	0.000996
P(X=4)	0.00000545	0.00000545	0.00000545	0.00000545	0.00000545	P(X=4)	0.00002159	2.159E-05	0.00002159	0.00002159	0.00002159
P(X=5)	0.00002183	0.00002183	0.00002183	0.00002183	0.00002183	P(X=5)	3.743E-07	3.743E-07	3.743E-07	3.743E-07	3.743E-07
F = 97	λ = 0.7913					**G = 7**	λ = 0.0609				
P(X=0)	0.4533	0.4453	0.4373	0.4293	0.4213	P(X=0)	0.9409	0.9329	0.9249	0.9169	0.9089
P(X=1)	0.3587	0.3667	0.3747	0.3827	0.3907	P(X=1)	0.0573	0.0653	0.0733	0.0813	0.0893
P(X=2)	0.1419	0.1419	0.1419	0.1419	0.1419	P(X=2)	0.00174	0.00174	0.00174	0.00174	0.00174
P(X=3)	0.03743	0.03743	0.03743	0.03743	0.03743	P(X=3)	0.0000354	0.0000354	0.0000354	0.0000354	0.0000354
P(X=4)	0.07405	0.07405	0.07405	0.07405	0.07405	P(X=4)	5.393E-07	5.393E-07	5.393E-07	5.393E-07	5.393E-07
P(X=5)	0.001172	0.001172	0.001172	0.001172	0.001172	P(X=5)	6.56E-08	6.56E-08	6.56E-08	6.56E-08	6.56E-08

Appendix VIII: List of Thesis Research Output/Publications

- **February 2018: Climateproofing the Future of Resources, Ports and Supply Chains. What Africa Could Learn From South Pacific Climate Change Resilience! (**Adaptation Futures International Climate Change Conference, Cape Town).
- **January 2018 Overcoming Psychological Barriers. Persuading Pacific Maritime Supply Chain Stakeholders To Prioritise Climate Change Resilience:** To be published as peer reviewed book chapter in "**Handbook of Climate Change Resilience",** Springer Press.
- **October 2017: Identifying Some of the Opportunities Offered By Climate Change to Small Island Developing States,'** (Journal co-authored article under review).
- **July 2017:** The following paper has been accepted for the **World Symposium on Climate Change Impacts and Adaptation Strategies to Coastal Communities, Apia Samoa (Based on Thesis Chapter 5). 'Predicting True Climate Change Risks and Opportunities in the Cook Islands: How Vulnerable Are Pacific Maritime Supply Chain Stakeholders?'** (Peer reviewed book chapter in **"Climate Change Impacts and Adaptation Strategies in Coastal Communities" Springer Press.**
- **June 2017:** The following papers have been accepted for publishing in the IAME 2017 Conference Proceedings in Kyoto '**Projecting The Future Of Pacific Ports, Shipping and Maritime Supply Chains: Evolving Climate Change Risk Management into Risk Opportunities' (Chapters 5/7)** and **'How Risk Management Fails To Protect The Global Quality of Maritime Supply Chain Trade Through Climate Change Impacts: A Critique From The Literature' (Chapter 2).**
- September 2016 '**Predicting Climate Change Risks For Pacific Maritime and Coastal Infrastructure,' (Chapter 3)** Presented at the 12th ACCARNSI Conference/ECR Researcher Forum, University of South Australia (Awarded Scholarship by CSIRO/ACCARNSI and Invited PHD Student Speaker).
- July 2016 **"Climate Change: Risks, Costs and Opportunities For Global Maritime Supply Chains," (Chapter 2/3)** Presented at the Australian National Climate Change, Adaptation Research Facility Conference, Adelaide (Awarded University of Adelaide, Vulnerable Community Network, Adapt 2016 Scholarship).
- July 2016 **'Adapting Climate Change Projections to Pacific Maritime Supply Chains," (Thesis Chapter 4)** Presented at the University of South Pacific, Pacific Climate Change Symposium, Fiji, and accepted as a peer reviewed book chapter "***Climate Change Adaptation in Pacific Countries: Fostering Resilience and Up-keeping Life Quality in Pacific Countries"***, Springer Press.
- September 2015 **"The Impact of Climate Change on Pacific Maritime Economies: An Introduction:" (Chapter 1)** Presented at the University of Tasmania, Graduate Research Conference, Hobart.

Appendix IX: Climate Change Risk Management Method Thesis Notes and Contributions

This appendix expands upon the hypothesis developed in chapter 3 that existing risk management methods, theories and research fails given climate change uncertainty as this thesis contribution. This derives from IAME 2017 paper I (Appendix VIII.) For the conventional Figure 3.1 risk management approach stages below; it summarises specific issues, when applied to climate change risk events.

How Risk Management Fails To Protect Maritime Supply Chains Through Climate Change Risk Impacts: A Literature Critique.

Abstract
Prospects for the global quality and future of marine economies, shipping and seaports have never seemed so uncertain. Global marine economies and supply chains face significant commercial challenges to facilitate trade, ensure profit maximisation, cost recovery, environmental sustainability and securitisation against increasing disruption risks throughout all stages from producer to consumer. Significant legal, environmental, commercial, political, social and physical risks all threaten the quality of maritime trade and other key stakeholder requirements. This conceptual paper's research contribution in a critical literature review, issues-based method approach considers if climate change risks have been sufficiently analysed and prioritised for marine economies, systems and stakeholders. Its findings identify, whilst existing marine stakeholders, journals and methods have prioritised disruptions, from strikes, inventory disruptions, port congestion, financial crises, terrorism to accidents; climate change is not a current research priority. It considers a systematic, methods based critical literature analysis to answer how risk management literature/methods currently fail to protect marine economies from projected climate change risks. This establishes current research journals' failure to guide policy stakeholders and academics, with the need for new methods, case studies, research, policies and solutions to minimise stakeholder and academic uncertainty over climate change risks for marine economies.

Keywords: Marine economy, risk management theory, climate change

Introduction

From producer to seaport to consumer, the global quality of future trade and marine economies are threatened with disruption and extinction. Stakeholders continue under business as usual scenario forecasts utilising conventional risk management tools, assuming these are sufficient to protect each stage with minimal impact and opportunity cost and mitigation is adequate to respond to climate change uncertainty. According to the United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP 2015), the world economy lost over $2.8 trillion based on climate-change related events in direct physical infrastructure damage from 1970-2014. Each year is expected to cost a minimum of $250-300 billion in direct damage, without considering disruption or adaptation costs. Climate change with projected changes in temperature, sea level, precipitation, wind velocity, currents, storms, droughts, cyclones, tsunamis and landslides establish the greatest uncertainty for the future survival and sustainability of related ecosystems, species, economies and populations, commodity resource bases, levels of coastal protection, economic activity and seaborne trade (IPCC 2015). In 2005, Hurricane Katrina cost over $150 billion in impact costs. Solomon Islands, 2012 floods cost over $55 million in taro crop production, residential property and physical infrastructure damage alone, from demolished natural ecosystem, climate protection barriers e.g. mangroves and sand dune erosion (SPREP 2014). Yet as this critical review emphasises; significant uncertainty exists for specific, climate change risks for marine economies. Supply chains will experience increased vulnerability, reduced resources, lower demand, disruptions to supply resources, infrastructure, performance, prices, profits, costs, people and ecosystems. This necessitates greater stakeholder awareness and prioritisation of adaptation over other disruption risks to ensure long not just short-term survival. Yet stakeholder, climate change awareness remains the least prepared, least studied risk both among policy makers and academics, especially for global marine economies (SPREP 2014; IPCC 2015; UNISDR 2015). This paper's research contribution identifies existing literature gaps for risks, integrated with marine economies so key researchers and policy stakeholders with scarce time, financial, skills and other resources, prioritise risks to reduce uncertainty and potential disruption costs. It will enable future researchers to concentrate on climate change as an emergent risk.

This paper therefore seeks to answer Key Research Question A: Does current literature sufficiently recognise climate change risks for marine economies and stakeholders? This is answered through an issue based, systematic critical literature review method in response to a specific research question/hypothesis and pre-defined exclusion criteria. Issues focus on risks for ports, shipping and entire economies identifying existing findings' advantages and limitations. Its originality and value proposes revisions to risk management theory, as the first paper to specifically consider defining an entire marine economy's conceptual framework and characteristics for climate change risk management. It further aims to answer Key Research Question B: 'Are risk management methods, theory and research sufficient to adequately protect marine economies from climate change risks?' This will be answered through a systematic literature review analysis analysing specific methods, in response to a specific research question/hypothesis and pre-defined exclusion criteria. The remaining article provides the issues-based review method for research question A and method review for question B, review findings, conclusions, implications and proposed directions for future research. It considers conceptualising adaptation strategies across marine economies systematically, from a stakeholder requirement, perspective, rather than isolated adaptation efforts for individual stakeholders and stages in current literature.

To address these key research questions this article considers the research advantage of a more focused, consistently systematic, critical literature review method and conceptual theory paper to justify its research significance. It establishes the further need for an integrated, climate change method and adaptation strategies for global marine economies, systems and stakeholders. Whilst existing risk management theory considers global economy, disruption risks, these have primarily concentrated on landside stakeholders, resources and economic activities (Kern *et al.* 2012, Kazemia and Szmerekovsky 2015, Hasania and Khosrojerdib 2016). Given over 90% of global trade is seabourne, many island states and coastal communities are marine economies, with virtually no land based economic hinterland or stakeholders, being highly dependent on seaports and shipping whose economies and livelihoods completely dependent from production via fisheries to transport by sea and exports. These are dominated by maritime ecosystem resources including seafood and pearls in trade, with significant maritime asset interdependency, highly vulnerable to ocean and climate risk sources. This paper is among the first to distinguish these Figure I marine economy characteristics as its contribution. To understand how risk management especially fails to protect marine economies, this paper specifically concentrates on related characteristics with maritime supply chains, resources, systems, infrastructure, stakeholders and ecosystems. It considers existing theory prioritised by current researchers and journals to have failed to protect marine economies from existing and projected climate change uncertainty, ignoring significant maladaptation, opportunity or potential inaction costs for stakeholders. It aids future researchers and provides practical policy guidance to stakeholders seeking to concentrate on this emergent risk, whether through applying existing risk management theory or in devising new conceptual frameworks, when formulating a risk response for the future commercial survival of marine economies. This aims to overcome current risk management theory failure to prioritise a significant emerging risk.

Figure I: A Marine Economy

See Figure 2.1 in main text

Source: Dyer IAME 2017

2: Systematic Literature Theory/Methods

To address Research Question A this article applies an issues-based literature review analysis method into related maritime, economic, business, supply chain and risk management studies. To ensure relevance, keywords including "climate change' 'risk management,' 'economic impact' and 'ports/shipping/transport/supply chains was applied to these areas and then continuously updated as relevant studies were located. The search also utilised various databases including SCOPUS, Web of Science, Google Scholar and Academia.edu. The search found no specific sources related to climate change risk management and marine economies for question A. However, it reviewed 912 potentially related journal articles sources based on the above exclusion criteria for SSCI rated journals. These were considered to be of most value to researchers, policymakers and stakeholders. From 100 sources reviewed only 27 provided potentially relevant methods to consider applying to marine economies for question B. Reviewing climate change risk, impact and adaptation methodology literature from UNFCCC (2012), Chhetri et al. (2013), Scott et al. (2013), IPCC (2015), Ng et al. (2017) and over 200 generalised variations on method approaches (Pinto, Kay and Travers 2008) confirmed researchers proposed methods. However, these failed to provide empirical case studies specifically related to marine economies/supply chains to validate risk management. A systematic literature review provides research advantages of more focused insight into research questions. To answer Key Research Question B, a systematic review is also applied but for critical summaries and evaluations of existing risk management research methods/theory. The reviews aim to identify and evaluate relevant research gaps, strengths and weaknesses, a systematic review approach supported by Partusso et al (2012).

3. Findings: An Issues Based, Systematic Review: Climate Change Risks and Marine Economies

This paper's systematic review method considers current literature insufficiently recognises climate change risks for marine economies and stakeholders as a research priority for question A. The most commonly cited research journals possessing the highest impact factor from 2000-2016, in maritime affairs, logistics, business, transportation and risk management in Table 1, however failed to identify climate change as a risk as a significant priority of existing researchers and publishers. These focused on other risks including strikes, inventory disruptions, port congestion, financial crises, terrorism and accidents. However, these challenges are investigated extensively by existing research and risk management sources with established resilience and recovery guidelines to which stakeholders can adapt. Despite increasing uncertainty over climate change risks for risk management, economies and marine related areas, affecting future risk management for these stakeholders and overall systems, climate change remains ignored and underestimated by these areas across 912 articles across 17 years and 11 Table 1 journals. Additionally, the top 50 SCIMAGOJR transport journals, 50 business journals and 33 risk related journals across issues and 17 years also continuously ignore climate change as a key risk and how risk management methods fail for climate change whilst ignoring marine specific contexts. These sources further ignore systematic shock. Equally, existing climate change research ignores marine sector/empirical based risk management. This affirms question B's hypothesis how existing risk management methods not only ignore and underestimate these risks/impacts but fail to protect marine economies and stakeholders, in not appearing as a risk concern/priority in established journals. With limited stakeholder/researcher, climate change risk awareness, inconsistent definitions, methods, equations, strategies and no existing case studies with empirical probabilities of risks occurring or calculated impact costs to assist stakeholders and researchers, existing literature/methods fail significantly to rectify disruptions.

Table 1: Risk Management In Relevant High Impact Factor Journals 2000-2016.

Journal	Impact Factor	Disruption Risk Management Factors	Author, Year
International Journal of Logistics Management	1.07	Environment, social, political, demand, supply, process, control Organisation, Network, Holistic	Christopher and Peck 2004 Jüttner 2005 Ghadge and Kalawsky 2012
International Journal of Physical Distribution and Logistics Management	1.93	Outsourcing/Offshoring Inventory reserves Inventory, supplier-buyer relationship Operational and disruption/disaster risks	Grimm *et al.* 2015 Son and Orchard 2013 Wieland and Wallenburg 2012 Kern *et al.* 2012
International Journal of Shipping and Transport Logistics	0.85	Extreme weather Port congestion Security Piracy	Doll, Papanikolaou and Maurer 2014 Trepte and Rice 2014 Jażdżewska-Gutta 2014 Wong and Yip 2012
International Journal of Transport Economics	0.548		No relevant authors published
Journal of Business Logistics	1.83	Supply Internal	Kaki, Salo and Talluri 2015 MacDonald and Corsi 2013
Journal of Supply Chain Management	3.86	Environmental, Organisational, Individual Transaction –Supply and demand	Ellis, Shockley and Henry 2011 Wever *et al.* 2012
Maritime Economics and Logistics	0.773		No relevant authors published
Maritime Policy and Management	1.22	financial flows, transport, communication, internal operations/capacity, labour customs, port strikes, equipment failure Earthquakes, oil spills/accidents, labour Natural disasters, port disruptions labour, social instability	Berle, Rice and Asbjornslett 2011 Gurning and Cahoon 2011 Omer *et al.* 2012, Hsieh, Tai and Lee 2014 Lam and Su 2015
Supply Chain Management: An International Journal	3.50	Production outsourcing Price Reputation	Tsai, Liao and Han 2008 Fischl, Scherrer-Rathje and Friedli 2011 Petersen and Lemke 2015
Transportation Record Part D	1.94		No relevant authors published
Transportation Record Part E	2.68	Terrorism Operational, supply and demand Food contamination Natural disaster crop disruption	Bueno-Solanoa and Cedillo-Campos 2014 Sadghiania, Torabib and Sahebjamniab 2015 Chena, Liub and Yangc 2015 Yanga and Xub 2015

Source: Dyer IAME 2017

Whilst existing climate change risk management and impact studies have focused on regions, ecosystems, land economies, populations, health, communities, agriculture and aggregate economic sectors only a few recent supply chain and no marine economy examples exist. These have mainly concentrated on ports, shipping; intermodal transport and general supply chains as separate stages rather than a system perspective. In failing to define and recognise both risk event types and associated impacts as an issue in existing studies; current stakeholders are often climate change risk adverse, failing to adapt to risk uncertainty according to Becker et al. (2011), Seto et al. (2013) and the United Nations Economic Commission for Europe (2014) for international transportation networks. Becker et al. (2011) proved among the first to utilise a qualitative research, perception-based survey to identify climate change disruption risks, impacts and adaptation solutions for seaports, consulting 208 International Association of Ports and Harbours stakeholders with 93 responses. 53% considered climate change would affect them but 88% agreed more research was necessary to understand its impacts. However, it primarily concentrates on port administrators rather than other maritime businesses/marine economy examples and being qualitative does not provide specific risk management case study examples. UNCTAD (2011) similarly used a survey instrument among its 200 members to identify port vulnerability to climate change risks and associated stakeholder adaptation responses. McEvoy and Mullet/Chhetri et al. (2013) utilised workshops as an alternative qualitative method designed to ascertain Australian port stakeholder perceptions and actions over adapting to climate change risks and impacts. Findings indicated limited climate change risk awareness as an issue for 3 ports. The source ignored extending a proposed vulnerability-risk assessment method and stakeholder consultation approach across the entire supply chain/marine economy system,

Industry assessments of adapting supply chains to climate change include CSR (2011) and BSR (2015) rate it low as a priority for effective risk management. These argue for specific case studies/methods based on numerical risks, impact costs and adaptation solutions to extend beyond surveys and interviews for climate change mitigation. From reviewing Fussel (2007); Granderson (2014); National Cooperative Freight Research Programme (2014) for climate change impacts on transport; this article contends a qualitative interview/survey-based approach commonly assumes these stakeholders are accessible and informed. Existing survey methods i.e. Thornes (2012 for a United Kingdom transport sector, climate change risk analysis) primarily concentrate on developed countries/land-based economies, assuming significant financial, skilled labour, time, information and other resources. However, the time, resources required and complexities involved in establishing direct stakeholder consultation, provides significant constraints to field research, particularly among geographically isolated/large distances of small Pacific archipelago, marine economies. Several climate change survey studies including UNCTAD (2011), and Kreie (2013 for global supply chains), also selectively ignore key marine economy stakeholders as economically peripheral or involving too much time, resources and effort to incorporate a risk event's economic impact in study methods. However, this paper agrees with Becker et al. (2011) that climate change impact and adaptation strategies can no longer be constrained to just consulting direct port stakeholders involved. Ports alone are insufficient and uninformed to resolve potential event disruptions for marine economies. They reflect only one type of marine economy business.

In recognition of existing literature theory failures to integrate climate change with global general and marine economies for risk management, this paper's conceptual contribution proposes identifying existing risk exposure to emphasise the need to prioritise this emergent issue. It highlights existing individual marine economy/supply chain stage risks, associated impact costs and adaptation challenges prior to evaluating existing risk management method failures to protect from individual and systematic risks. This paper identifies two recurrent risk types based on time horizons. Forfas (2010) and Thomas, Albert and Perez (2013) focus on physical risks as disruption risk events with long term impact effects/changes including sea level, land, sea and atmosphere temperature, current, wind velocity rise, changes in sedimentation and wave energy. These often require less immediate priorities, constraints and mitigation or adaptation strategy responses over a time period of years, decades or longer. A second identified category focuses on unpredictable disruption risks with short term, sudden impacts. Table 2 examples include climate change-related, natural disaster events e.g. storms, tsunamis, typhoons, cyclones, droughts, heatwaves and landslides. These present greater, more direct risks and impact costs that necessitate short term adaptation, resilience and mitigation strategy responses, presenting a threat over a year or less. This article exclusively identified another climate change disruption risk changes in species migration and biodiversity loss which possesses unconsidered, impact costs for affected stakeholders. In failing to define and recognise both risk types in existing risk management studies; current stakeholders are often climate change risk adverse, failing to adapt to risk uncertainty (Becker *et al.* 2013; Sadghiania, Torabib and Sahebjamniab 2015). Concentrating on a single risk type underestimates potential impacts increasing eventual disruption and adaptation costs involved, if response actions are not perceived as necessary by stakeholders. To address marine economy disruption risks for stakeholders, this paper considers it necessary to include both short/sudden and long term, risks as an integrated theory, as numerous sources focus only on one time horizon, either relating to long term risks or an extreme event's short-term impact (Brooks *et al.* 2012; Sekimoto *et al.* 2013).

Table 2. Climate Change Long Term Impacts for Marine Economy

Gradual Physical Climate Risk Events	Impacts on Port	Impacts on Shipping	Impacts For Maritime Supply Chains
Sea Level Rise	-Increases in coastal erosion/ -Reduced port and surrounding economic hinterland/supply chain physical land area and access. -Physical damage and weakened climate resilience from potential flooding for port infrastructure, equipment and services. - This creates increased repair, maintenance and replacement costs	-Increased water depth/reduced bridge clearance creating changes in vessel navigation route and minor increases in fuel/bunkerage costs	-Physical damage, delay, congestion, financial and opportunity costs to individuals, cargo, property, equipment and port functions to all supply chain stakeholders for all risk events Changes in -Inputs/Resources, -Labour -Processes -Production Outputs -Outsourcing -Distribution/Sales -Access to Financial Capital -Profits and Costs -Customs processes -Legislation
Precipitation	-Increased duration creates flooding and increased surface runoff creating temporary/permanent physical damage, delay and other port disruption costs. -Increased damage to exposed physical commodities and port equipment This creates increased port and related supply chain performance delay and impact costs	-Increased precipitation may discourage strategic vessel callers. -Increased physical vessel fatigue, commodity damage and reduced navigation –increased vessel delay/slow steaming, insurance, costs	
Temperature/Humidity increase	-Weaker structural infrastructure resilience and possible physical damage oxidation and corrosion increasing over time. -Potential health/safety risk to port labour, equipment, management and technology decreasing port performance	-Potential physical commodity damage and increase in energy consumption of reefer/containerised cargo throughput	
Wind velocity	-Risk to cargo handling labour, container stacking crane gantries, equipment	-Risk to physical vessel docking, pilotage, tugs turning basin movement	
Change in currents, wave energy, ocean acidification and sedimentation	-This disturbs port ecosystems and physical risk exposure; maritime resources and habitats affecting related commodity yields.	-Alters water flow, complicates vessel navigation, higher tug mooring and pilotage costs. Increased hull cleaning, maintenance and repair costs.	

Source: Dyer IAME 2017

Projected long term risk events and associated impacts/consequences threatening ports, shipping and other marine economy stages are summarised in Table 2. Short term risks are summarised in Table 3 from existing literature (Omer 2012; Becker *et al.* 2013; McEvoy and Mullet 2013; Hsieh, Tai and Lee 2014; Esteban and Takagi 2015; Scott *et al.* 2013). These authors once more focus on qualitative impact descriptions for ports ignoring other maritime business/marine economy risks This review agrees with IPCC (2015) and UNISDR (2015), that sudden, short term risks provide similar damage and other impact costs to long term impacts differing primarily through greater physical, economic, psychological, health, reputational, environmental and other direct/indirect impacts on demand, capacity and performance throughput for a greater time duration, frequency and intensity. The most significant impact costs are considered those to life and property establishing a loss of economic potential from disruptions to production, consumption, management and labour (particularly for primary commodities), reducing supply capacity for cargo throughput). This reduces port revenue and physical capacity to undertake functions with adverse significant supply chain implications via contractions in trade/marine economic activity. More significant risk events possess more immediate and costly, direct impact consequences, mostly requiring more urgent and decisive risk management action by affected marine economy stakeholders. Physical damage to port infrastructure, vessels, equipment, cargo and related utilities (water/electricity/sewerage) is projected to establish significant damage to infrastructure, services and performance and quantity of cargo throughput exported, imported or transhipped through a port.

Therefore, given the absence of climate change as an issue in existing related journal or a priority of researchers; yet significant risks/impact costs projected for specific marine economy stages including ports and shipping; this research considers current literature highly fails to sufficiently recognise climate change risks for marine economies. Ng et al. (2015) also mention an indirect effect of increasing public climate change awareness has increased the influence of environmental activism in boycotting commodities e.g. coal for Australian ports. This creates a further increasing supply/decreasing demand impact risk for each dependent economy stage. Certain customers however may be more receptive to possible disruption risks, reducing potential reputational risks. According to Linennluecke, Griffiths, and Winn, (2013) outlined in Table 3, climate change is likely to influence supplier decisions of sourcing material cost, type (if climate sensitive), quality and quantity including factors e.g. water supply, geographical location, distance, size, environment and physical exposure to risk, negotiating, buying/pricing, strategic demand and supply. Lee and Kim (2013) consider how customer demand and producer supply expectations or requirements may shift in adapting, affecting pricing, sales, distribution, order management, fulfilment and distribution along with the degree of customisation that port users might require, to become potentially more or less flexible in response to climate change. The speed at which a supply chain stakeholder can satisfy demand, to provide services, alter schedules and requirements, being responsive, adjusting the price and quality/quantity of services globally, is considered to increasingly depend upon the extent to which they prioritise adaptation and resilience by an increasing number of sources e.g. Network for Business Stability (2011), Linnenluecke, Griffiths and Mumby (2015) and Ng et al. (2017).

Table 3. Short Term, Sudden Climate Change Impacts for Marine Economies

Sudden, Short Term Climate Risks	Impact Costs on Port	Impact Cost on Shipping	Impact Costs for Maritime Supply Chains
Storms/Superstorm surges	-Increased threat to communications, information and early warning systems	-Physical vessel/port /commodity damage. -Physical danger to vessel navigation.	-Risk Changes in Species Migration/Biodiversity -Changing Rate of Innovation and Technology -Global economic activity -Changes in Seaborne trade -Changes in access to maritime finance -Changes in global and regional social-political/commercial/ environmental instability -Increase in insurance premium costs -Changes in economic demand, supply and associated changes in economic activity, employment, production, consumption, exports and imports, inflation and exchange rates affecting purchasing power and trade competitiveness.
Hurricanes Cyclones Tsunamis	-Physical damage to port infrastructure, to vessels, equipment, cargo and related utilities. These create increased construction, repair, maintenance and replacement costs -Possible physical commodity damage decreasing a port's reputation loss risk/creating increased insurance costs from reduced business confidence -Psychological Costs, Threat to life and property, creating a loss of economic potential, commercial profits, tax and port revenue -Higher Port Costs	-Higher insurance premium, repair, maintenance, labour, voyage, charter and other costs, -Reduced port access, increased congestion, -Physical navigation risk -Threats to vessel navigation, safety, delays and congestion.	
Droughts	-Physical threat to agricultural and fishery productivity reducing potential cargo throughput. -Lower water depths may limit channel/port navigation and related vessels -Physical threat to providing port bunkerage, fuel and other services.	-Changes in demand, supply, port profitability and pricing -Changes in routes, markets, trade diversion and reduction	
Heat waves	-Physical threat to port productivity – health and safety of affected workers creating idle capacity and other delay costs -Direct threat to physical fatigue of infrastructure, equipment and operations delaying port activity -Damage to information/ communication systems	-Production variations in demand and supply reducing cargo throughput and revenue	
Landslides	Increased soil moisture from precipitation, storms, tsunamis and cyclones can destabilise road/rail/ coastal erosion creating congestion delays from debris. Public Health Risks from exposed waste disposal sites.	Physical legal and technical regulatory compliance costs, Increased insurance liability costs Production variations in demand and supply through submerged crops, port, transport and storage infrastructure, reducing cargo throughput and revenue	
All Risks	Operational/financial and reputational cost loss	Operational/financial and reputational cost loss	Changes in port pricing, taxes, subsidies to recover costs and finance adaptation

Source: Dyer IAME 2017

From Pacific case studies (SPC 2013), this literature review indicates the economic-financial impact cost challenges in disrupting any commodity include increased customs, cargo handling, storage and distribution, port authority and transport delay, time and opportunity/reputational impact costs. Climate change financial impacts threaten commercial profits and port revenue from possible port congestion, creating risk and uncertainty for all dependent stakeholders adversely influenced by loss, damage or postponement to trade. Additional indirect impact costs to port authorities and other marine economy stakeholders from climate-change consequences include threats to agriculture, aquaculture, forestry, transport, infrastructure, cargo, equipment and the overall economy. Examples include lost wages, business delays and interruptions, increases in operational, risk management, training and capital expenditure associated with port recovery. Fewer callers and reduced cargo throughput will create correspondingly reduced tax revenue for government stakeholders, reducing potential budget expenditures and creating indirect opportunity costs to other stages and economic activity levels. Additional increases in climate change adaptation strategy costs are further anticipated to reduce commercial viability and sustainability for shipping operations and stakeholders directly.

Finally; this review advocates the most significant marine economy stage that still needs incorporating in a conceptual risk management theory affected by short term risk events and associated impacts includes access to financing and capital investment sectors for climate change adaptation (Linnerooth-Bayer and Hochrainer-Stigler 2015). New production, consumption and investments will be constrained by an increasing reluctance of the risk adverse global financial sector to increasingly invest based on increased uncertainty, asymmetrical information over potential disruption risks, sacrificed or delayed profits. This will deny commercial and investment opportunities for producers, shipping companies and other transport distributors, retailers and access to consumer credit for customers. Climate change also threatens insurance companies and financial sector solvency. This influences other economy/supply chain stages capacity to transact/perform. Assessing direct and indirect impact costs from increasing risk exposure of an increasingly globalised and interconnected, further complicates potential resilience adaptation strategies to extend beyond individual stakeholders, businesses or ports. However, this article proposes the ultimate economic impact threat that climate change possesses for stakeholders, includes the submergence of substantial sectors of (or entire) Pacific nations and economic markets. Companies may have to diversify rapidly into new routes or markets, new consumer demand and supplies, diversifying into multimodal transport opportunities, to exploit trade diversion from those failing to adapt, to enhance financial and shipping market risk resilience. Given these cost implications; this research's conceptual significance is justified and affirms current literature insufficiently recognises these climate change risks for marine economies and stakeholders.

4: Findings: A Methods Based Systematic Literature Review

Risk management method characteristics identified in existing climate change risk management studies utilising probability distributions aim to estimate risks on various activities, systems, stakeholders, assets or infrastructure, (though not combined for entire marine economy systems), (Rehdanz 2004; Simpson et al. 2010; Australian Department of Climate Change and Energy Efficiency 2012). However, very few examples satisfying these characteristics with actual values and equations provided have been located for marine economies from over 900 references (even for individual stages), further emphasising this paper's significance. Existing risk management research generally ignores providing equations, empirical probabilities, risk management model characteristics, assumptions and probability distributions for stakeholders to protect marine economies, proposing standard risk assessment methods, results and solutions based on qualitative data. To answer KRQB, however, this method's based systematic literature review considers risk management methods, theory and research insufficient to adequately protect marine economies from climate change risks for the following reasons.

Although existing risk management literature fails to provide a coordinated unified risk management theory, this review identifies similar theory characteristics when considering how risk management fails to protect marine economies from climate change. Risk is consistently defined as the repeated probability or likelihood of an event occurrence combined with its consequence (IPCC 2015). Ghadge and Kalawsky (2012) define risk as exposure to an event adversely affecting efficient supply chain management. Effective risk management theory aims to minimise disruption events, associated risks and impact costs to enhance resilience and robustness, reducing recovery time (Wieland and Wallenberg 2012). It is considered dependent on stakeholder vulnerability and agility or the ability to swiftly adapt. Jüttner (2005) and Kern *et* *al.* (2012) propose risk identification, assessment and mitigation as three essential stages to managing risk as a linear series of interdependent relationships along marine economy stages from producers to consumers. Ellis, Shockley and Henry (2011) consider uniting divergent approaches including real options approach (which postpones risk mitigation or treatment to address uncertainty through more informed decision making), transactional costs (balancing supply and demand disruptions simultaneously) and resource dependence theory, (which bases effective risk treatment as conditional on the resources available), with one based on economy/supply chain stakeholder psychological behaviour over risk perceptions, as current risk management theory methods.

Standard risk management theory approaches include cause and frequency analysis, Bayesian networks, HAZOP, What If? Monte Carlo simulations, VAR, real options approach, transactional costs and resource dependence theory and risk event/fault trees (Ellis, Shockley and Henry 2011; Kern et al. 2012, Ghadge and Kalawsky 2015). Examples include Hawkes et al. (2010), Mitsakis et al. (2013) and Paeniu et al. (2015) concentrate on assessing risks and vulnerabilities, based on stakeholder's perceptions over the probability/likelihood of a risk occurring and consequences. Ng et al. (2017) target current vulnerabilities and future risks for several port case studies as an alternative risk evaluation method combining risk management and vulnerability but focusing on socio-economic factors affecting risk including demographic growth, technology, economic and institutional policy change as scenario inputs; rather than specific climate change risks. They detail how alterations in risks can generally disrupt port operations. However, they completely ignore marine economy/maritime supply chain context specific examples and provide few empirical case studies that rely on physically calculating projected climate change risk consequences. Providing multiple risk management methods recommending stakeholder risk identification provides unreliable risk expectations, given demographics/experience. It indicates climate change risk perceptions not actual risk measurement using empirical data as to whether climate change risks present a continuously increasing threat. Ng. et al. (2017) also fail to evaluate how effective existing risk management approaches are, providing no post risk-adaptation/measurement studies assessing impacts on performance/other criteria.

Lam and Su (2015) also model disruption through risk against its projected outcomes or consequences with various adaptation strategies for Asian ports as indicative of a general trend of how standard risk management fails to protect marine economies from climate change, specifically prioritising other risks. However, the work is flawed in multiple aspects in focusing on port specific areas rather than marine economies and an entire supply chain context. It provides no empirical case studies to validate findings and concentrates on other disruption risks without evaluation or prioritisation criteria, no connection to climate change projections and ignores multiple stakeholder relationships. It proposes standardised risk management theory flaws relying on subjective risk perceptions rather than objective data. All these sources and equivalent research currently prioritising climate change risk management incur method failures/issues e.g. complexities in forming probabilities (especially small island developing states/marine economy stakeholders); subjective understanding of risks, significant time, money and other resources required and providing unclear indications of how risk probabilities are calculated. The majority of conventional predictive risk models including existing event trees is that many are static (Ellis, Shockley and Henry 2011; Kern et al. 2012, Ghadge and Kalawsky 2015), assuming time remains constant or based on historic time series data. This ignores the projected rate or increase in the probability of an event occurrence, its duration, frequency and intensity and how risks can be multiplied thorough vulnerability, resilience, adaptive capacity, constraints to adaptation and increased interdependence, The most significant failure of risk management theory is illustrated in Table 1/other journals, where leading journals lack relevance ignoring climate change as the most significant disruption risk to maritime supply chains, stakeholders and logistics. Conventional risk management theory lacks consistent definitions over key concepts of risk management, resilience, robustness, mitigation, adaptation and method approaches. Without an integrated approach, stakeholders with scarce time, fiscal and other resources are pressured to interpret risks and consider which method to apply for multiple divergent literature approaches, as disruption costs exponentiate. Sources seldom consider potential similarities and differences in these impacts, risks and solutions per case study, ignoring climate change interactions and disruptions complexities; for an entire maritime supply chain system (Ghadge and Kalawsky 2012; Linnenluecke, Griffiths and Mumby 2015). Risk management fails, based on subjective risk perceptions in determining risk definition, methods, prioritisation and treatment without objective, consistent standards with which to assess risk treatment method effectiveness. From Naruse (2011) to Oster and Mainz (2012) to Wamsler and Pauleit (2016), this review observes myriad human perceptions exist over exact climate change implications, influencing different methodology approaches, risk estimations, impact costs, and potential solutions for affected marine economy stakeholders, processes, infrastructure and ecosystems. This causes stakeholders to underestimate or exaggerate associated climate change risk consequences. These risks add further uncertainty and asymmetrical information to developing countries especially small island Pacific nations e.g. Nauru, Niue and Tonga plus related marine economy stakeholders seeking to prioritise a response to climate change but lacking the resources, capacity and ability to afford maladaptation costs and responses, undermining perfect information assumptions of conventional economy risk management theories e.g. Hohenstein *et al.* (2015).

Whilst myriad mathematical risk management simulation models exist outside conventional risk management and probability theory, this article identified very few examples including Markovian chains that specifically apply to non-static disruption risks or climate change for marine economies or any supply chain, stage, commodity or stakeholder uncertainty conditions for supply chains. As simulation methods, approach characteristics include ascertaining variables under conditions of uncertainty to produce outcomes. An example is Gurning's application of Markov chains (2011) for an Indonesian-Australian wheat supply chain which modelled various potential maritime disruptions as a transition state and related causes including severe weather, security, port congestion, earthquakes, political events, port related equipment and customs clearance, yet ignored climate change as the most significant risk. Gurning also applied expected frequencies and risk probabilities for disruption management to minimise uncertainties and anticipate actual event consequences rather than physically replicating and testing risk conditions in objective reality. It also only focused on wheat not marine economy and climate/supply chain characteristics. It was based on stakeholder risk perceptions without considering the flaws of asking people's expectations of risk rather than measuring projected risk. However, disadvantages include impracticality of risk simulation methods for stakeholders with limited time, resources and information facing climate change uncertainty. Limitations include the scarcity of relevant model case studies; the complexity of isolating the total event impact for a single specific commodity, (even if economically significant) and in calculating various risks' specific impact cost magnitudes requiring econometric methods.

Other risk management theory flaws include generally failing to provide standardised definitions, assessment criteria and methodologies for climate change risks, probabilities and impacts on supply chains/marine economies. These rely on stakeholder perceptions rather than empirical data, conditional on differing, subjective, stakeholder perceptions over what risk, severity, vulnerability; resilience, impact, adaptation, likelihood and consequence mean for each consulted stakeholder and systematically to the affected marine economy. This article considers this necessary as an improvement over standard qualitative risk assessment models to assist and increase physical, psychological and institutional stakeholder adaptive capacity. Further risk method flaws include complexities in forming probabilities subjective understanding of risks, significant time, money and other resources required and providing unclear indications of how risk probabilities are calculated (especially for small island developing marine economies/supply chain stakeholders). Conventional risk management theory also fails to consider climate change, marine economy risks as a multivariate rather than linear relationship which connects all stages from producers to consumers. Complexities exist in identifying specific risk causes and effects for transactional cost risk models along with isolating climate from non-climate change risk factors, when calculating projected impact costs, evaluating risk and determining risk treatment. In revising risk management theory, possible disruption risks may affect (and be affected by) other interdependent assets, stakeholders and suppliers not just the actual marine economy process. In investigating Scott *et al.* (2013) and Ghadge and Kalawsky (2015) this article's further contribution to existing theory, redefines effective risk management, to understand a marine economy's intended purposes required before being specifically able to understand how all stages and stakeholders are potentially affected by climate change risk, As a method the advantages of consulting relevant stakeholders to ensure efficacious risk management recognises limited stakeholder information and resources, concentrating on preserving marine economy functional requirements, ignored by current risk management

Other risk management method current failures for marine economies include issues of asymmetrical information, unreliable and inconsistent empirical data and scenario analysis, oversimplification plus informational and situational bias based on initial model assumptions, hypotheses or parameters. Sources proposing methods including World Bank (2010), Dasaklis and Pappis (2013) and Cooper and Pile (2014); presume small island marine economies with limited labour, finances, technology, resources and information/time, are able to undertake research, can calculate risk probabilities and accurate, accessible, updated, consistent related information exists. However, assigning risks and calculating probabilities is constrained, given increasingly uncertain impact of global and Pacific regional climate change projections, being inconsistent and empirically unreliable; producing often conflicting results/methodologies in assessing associated impact costs. Additionally, existing risk management theory fails to protect marine economies by failing to provide a theoretical framework capable of projecting climate change risk events, in contrast to the case study proposed to validate this conceptual method in Section 5.

Unlike previous studies which provide generalised, qualitative descriptions of overall land economy, risk consequences and projected likelihood (Oswald 2011; Kiele et al. 2014), this overcomes existing literature gaps for specific marine economy stakeholders. Whilst risk identification is often proposed as a key essential stage, a systematic literature review established an absence of equations to calculate present and future risk events and ascribe probabilities or even to provide equations that calculate associated impact costs not just for this paper's specific focus of marine economies but for any supply chain stage, stakeholder or system. To calculate the average probability of a specific independent, future short term climate-change risk event occurring, this method proposes as its contribution to risk management theory; a measure that integrates the risk type, its probability of occurrence, its past data/potential accumulative risk, an event's frequency, its duration and climate change related/non-climate related factors that influence the probability of a risk occurrence along with the climate change scenario and time horizon. Specific climate change scenarios and time horizons can be verified scientifically through the IPCC while meteorological data is independently provided and consistently established by meteorology services, though the research devised specific equations are not detailed for this paper but presented elsewhere and recommended as a future research area.

This method provides the example of flexibility across time horizons, supply chain stakeholders and climate change scenarios, adjusting event probabilities and degree of confidence/results significance based on available and simulated data. Unlike previous risk management theory probabilities assuming the status quo remains over an event or asset's lifetime, this framework considers climate change risk events as fundamentally dynamic rather than static (merely reliant on historic time series data, given risk, uncertainty and climate change), including increases in yearly accumulative risks. An interaction or joint probability is necessary for calculating certain related events – i.e. historical correlation between storms and flooding; earthquakes, tsunamis and landslides; precipitation and storms, sea surface temperature/wind velocity and cyclones; earthquakes and volcanoes simultaneously. Risk concentration increases asset vulnerability, increasing the conditional individual/joint probability of an asset's failure. Accumulating risk considers taking existing climate change risk projections, which when estimated a given percentage range increase over 25, 50, 100 years, is converted to yearly percentage increases in alignment with stakeholders who consider risk preparation and management on an annual basis instead of an asset's lifecycle. This enables stakeholders, academics and policy makers to continuously improve probabilities over time with more reliable information. Each stakeholder's and researcher's perceptions of risk, likelihood and probability of an event occurrence and its significance; is conditional upon a number of factors including resources, education/training, degree of experience; physical risk exposure or vulnerability and resilience; identified in Figure 2 as necessary to calculate and measure true risk. It can incorporate resilience, vulnerability accumulated risk and factors affecting the probability of risk occurrence and adaptation costs

Figure 2. Climate Change Risk and Marine Economy Impact Event Tree Analytical Framework
Source: Dyer IAME 2017 See Figure 3.2 in main text.

5: Conclusions, Research Limits, Policy Implications and Directions for Future Research.

In conclusion; this paper presented 2 key research questions. To address KRQA, it considers current literature insufficiently recognises climate change risks for marine economies and stakeholders. A systematic literature review identified how significant existing research journals and academics fail to identify and prioritise climate change disruption risks in conventional risk management theory over other thoroughly researched risks, despite the increasing significance to future sustainability and survival of global maritime supply chains, stages and stakeholders. Conclusions are based on search criteria for high impact factor journals which stakeholders might depend upon for specific risk management methods and solutions for 912 articles in 11 Table 1 journals along with the top 50 SCIMAGOJR transport, 50 business and 33 risk related journals across issues and 17 years. Existing climate change risk management studies are port centred ignoring significant risks and impact costs to shipping, finance and other key marine economy stages, stakeholders and systems. It identified existing research has been land orientated, ignoring specific marine economy characteristics. It emphasised how in particular marine economy characteristics including resources, risks, stakeholders and requirements are even more under-prioritised and vulnerable than general economy/supply chains for risk management. This reviews' academic and policy implications establish the significance of potential maritime disruption risks and impact cost challenges, in extending beyond previous identified areas of impacts for ports and shipping/intermodal transport, across an entire marine economy. Increasing globalisation significantly multiplies risk and vulnerability for individual stakeholders and across supply chains. The impacts surveyed in established literature urge managers and other policy stakeholders consider these risks as a physical indication of the urgent need to act, to swiftly adapt to enhance potential survival prospects and minimise related externality/opportunity costs. This review considers being essentially reactive to events rather than proactive in climate change adaptation will significantly increase further disruption risks to global supply chains, ecosystems and communities from this uncertainty. Given IPCC (2015) climate change scenario assumptions and specific projections, this review considers to effectively manage risk; marine economy stages should consider adapting as soon as possible with new strategies and theories that recognise risks cannot be treated the same for all stakeholders.

To address KRQB, findings establish risk management theory has failed to protect marine economies from climate change risks in not appearing as a risk concern/priority in established journals with limited stakeholder awareness, no consistent definition, method, equations, existing case studies with empirical probabilities of climate change risks occurring or calculated impact costs to assist stakeholders and researchers. Current solutions inadequately address climate change uncertainty, particularly from increasing globalisation and marine economy interdependence. This article's managerial policy implications sought to familiarise marine economy stakeholders, lacking a current risk management theory framework and information; to ascertain the extent to which climate change is expected to disrupt each potential stage. It therefore seeks to overcome risk management literature and theory gaps for climate change risks proposing revisions to existing theory including equations to project current and future climate change risk, the conditional probability of a maritime supply chain asset/system failure and Figure 2 established multiple climate change dimensions. Future risk management theory can overcome existing research failure to sufficiently protect the future of Pacific marine economies and stakeholders.

This paper presents several research limits in being the first identified to prioritise how conventional risk management theory for marine economies, fails to consider climate change disruption risks. Space and resource limitations prevented an extensive literature review identifying all risks, impact costs and adaptation strategies for all stakeholders and stages, the development of a methodology and empirical case study. A future area of research proposes findings to identify and quantify the impact of climate change risks on a specific marine economy commodity. It also proposes existing risk management theories need to prioritise climate change. This paper also identified a significant existing research constraint as asymmetrical information over projected climate change impacts, establishing uncertainty for stakeholders prioritising adaptation; presenting a few examples and considerations to suggest possible future research directions. Finally, in response to conventional risk management theory failures; it proposes a future research direction should consist in devising an integrated methodology combining a risk-vulnerability management analysis method. This would include an empirical climate change impact cost analysis and coordinated risk management stakeholder adaptation strategies for individual stakeholders and across an entire marine economy, not just specific measures for individual ports and intermodal transport as a future research direction. This aids key academics and managerial/other policy stakeholders to minimise climate change disruption risks and reduce conventional risk management failures to prioritise a significant emerging risk to future marine economies, through an integrated interdisciplinary approach, as previous studies have separated risk management and climate change impacts.

Method Summary I: Define Objectives:

From the sources in Chapters 2 and 3, risk management defines risk as the expected likelihood or probability of an event occurrence combined with its consequence, yet the premise of likelihood based on risk perception is subjectively determined. No consistent definition exists to ascertain the source, extent and nature of risk including the specific context of climate change without a consistent definition for maritime supply chain stakeholders. It ignores the need to consider the underlying maritime ecosystem/resources affected by risk and which influences risk reciprocally along with causes, factors affecting the probability of risk occurrence, existing risk magnitude and how risk probability as consequences differ significantly from impact costs –being hypothetical rather than empirically certain. It does not demarcate consequences as direct, indirect and intangible and how these affect risk probability calculations and its extent.

II: **Risk Identification**

Risk management in being essentially concerned with static, existing risks rather than dynamic climate change risks, also ignores the distinction between long and short-term climate change risk types and implications for impact consequences, recovery time, asset failure rate and adaptation response, yet the need to consider the accumulative effect of both. Risk management bases itself on existing past risks without providing equations to calculate historic or future event probabilities nor considering Black Swan high impact, low probability events. It presumes such risk events are predictable based on past experience without considering new risks may emerge. It does not covey how to ascribe/calculate specific probabilities to specific risk events nor how to pragmatically obtain probabilities as data from supply chain stakeholders, whether in the context of a survey or specific interview questions/means of determining conditional probabilities of asset failure. It does not detail how probabilities can be constrained to that specific risk rather than others. No consistent definitions exist for using a Likert scale which assigns risk subjectively. Very Likely, Likely etc for most studies investigated, is inconsistently defined, if mentioned at all. When, where, why and how risks occur, are often ignored, providing no pragmatic guidance for stakeholders seeking to identify existing risk, even without contemplating future risk.

III: Risk Perception:

Given subjectivity of stakeholder risk perceptions, this thesis proposes this stage to consider the extent to which stakeholder risk awareness is actually measured accurately to minimise risk omission, under and overestimation and ascertain the validity of assigned probabilities. It proposes considering stakeholder identification of past risks – event frequency, duration and intensity/impact costs along with asset failure against existing risk events to provide objective risk identification criteria

IV: Risk –Vulnerability Analysis

Apart from inconsistent risk-vulnerability definitions and methods, existing risk management ignores how risks progressively affect each stage along with how MSC' asset interdependency complicates calculating specific risk probabilities and impact costs to isolate risk. It ignores accumulated risk, joint probabilities of risk event occurrence, assuming a univariate rather than multivariate relationship. Theory does not effectively link risk probabilities to specific impact costs to ascertain consequences necessary for projecting true risk, especially for climate change, when quantifying risks. It ignores how risks diverge across supply chain stakeholders, stages, systems, operations, asset types, risk event types, climate change emission scenarios and time horizons, capturing true risk potential and how risk, magnitude and consequences change over time.

V: Risk Evaluation

Theory ignores asset resilience, vulnerability, the influence of the underlying ecosystem and environment/climate upon the extent of risk and corresponding calculations of conditional probability of MSC asset failure from climate change risk events for Risk evaluation. It ignores future risks presented by projected climate change, competitors and interdependent supply chains further influencing conditional risk probabilities of asset/system failure.

VI: Risk Prioritisation:

No objective criteria exists for stakeholders with scarce resources to determine risk prioritisation for conventional supply chain risk management theory. Given Chapter 2/8 stakeholder adaptation constraints, established risk management theory often ignores which risks should be prioritised, how and why? Based on chapter 3 established selection criteria in Figure 5.5, this thesis proposes the previously identified short term and long-term climate change risks are prioritised for Pacific maritime supply chain stakeholders including the Cook Islands. Whilst the Cook Islands has more time to adapt related human, natural, technology, infrastructure, equipment, information, communication, system and other assets to long term scenario risks including precipitation, temperature, higher emissions and sea level rise, mitigation of emissions needs to be prioritised immediately to ensure supply chain and physical survival, avoiding even greater risks. MSC' stakeholders can prioritise short term climate change risks, avoiding uncertainty. For low probability, high impact risk events, considering projected increases in historic data initially, combined with climate change scenario, projected increased frequency, duration and intensity, counteracts stakeholder uncertainty as new risk types are considered highly unlikely by this thesis to emerge, so stakeholders consciously ensure they know how risks threaten individual operations, underlying ecosystem and entire maritime/general supply chain system.

VII: Risk Adaptation

Risk adaptation in conventional risk management theory sources maximises disruption risk duration and impact cost consequences. It is perceived as reactive rather than proactive theoretically and when applied by stakeholders, frequently ignoring previous experience/other risk events. Conventional risk management ignores opportunity, recovery, repair, ecological rehabilitation and maladaptation costs along with constraints to adaptation. New solutions are often proposed or the same solutions repeated, mirroring/duplicating existing research wasting past research rather than consulting stakeholders/considering existing research gaps.

VIII: Risk Management: Monitoring and Review

Orthodox risk management generally considered theoretically a good idea but from the references reviewed for Chapters 2/3 search criteria, no empirical post risk management studies exist as implemented to consider if risk management has succeeded or failed effectively along with no post-feasibility studies often due to resource constraints. This method stage is often mentioned but with no objective methods or criteria are provided, especially to ascertain the reliability of probability and impact cost calculations, revising estimates to enhance accuracy Risk management often ignores potential efficiency and experience gains when considering risk management/potential loss of experience/resources and how existing risk management may sufficiently influence future risk management –theory and practise. It ignores existing experience/research, duplicating potential resources, instead prioritising what is really necessary. It ignores stakeholder requirements and does not incorporate how others have responded to other disruption risks, instead of prioritising what is really necessary. It insufficiently considers the change nature of risk due to different circumstances.

'Managing risk,' infers readjusting to normal conditions and a stable long run equilibrium or 'business as usual,' whereas IPCC 2015 climate change projections infer multiple extreme events increasing in risk frequency, duration and intensity as the new normal, where conditions may not be normalised or stabilised, especially if emissions are not substantially reduced and the underlying maritime ecosystem restored. Risk management does not consider climate change risks of extinction, depletion of resources and collapsing ecosystems or risk events with multiple causes, impact consequences or factors affecting risk., scenarios and confidence intervals or even if whether the risk itself is recognised and treated if one. Risk Management often ignores the role of stakeholder consultation, learning and how to overcome existing challenges of stakeholders in sufficient and accurate risk determination, the role of psychological expectations influencing risk probability and impact cost consequences estimates and relationships/connections with the extent of multiplying/reducing risk based on pooling resources. Risk management merely considers existing scenarios as the extent of maximum possible risk, underestimating worst case examples. It ignores failure and success in risk management and how risk probability/impact costs are subsequently modified. It assumes people will and can monitor asset/system risk event history and ascribe values. Long run equilibrium assumes constant growth rates, a supporting population, functioning economy and resources able to effectively monitor, respond, identify and adapt to risk events over time, ignoring climate change which infers risk adaptation and resources are sustainably secured whilst still possible. It presumes all method steps are possible –and are possible in that order, sequentially not simultaneously –of multiple risks occurring. It concentrates on operational/systematic risk rather than other risk types and considers risks generically rather than diverging being event specific in probability and consequence but often sharing certain risk generic characteristics. It does not consider if the probability of a risk event can be changed. It fails criteria of reliability, accuracy and objectivity

Thesis findings affirmed that whilst sufficient data may exist relating to general climate change risk events; there is no data or specific techniques that has been specifically provided in the perspective of disaggregated Pacific MSC,' climate change risk conditional probabilities –as the thesis's conceptual empirical and theoretical contribution. Whilst it might be possible to a minor extent to consider risk probabilities based on insurance for major government infrastructure/ assets/ larger vessels and private sector company assets; field research would be necessary to ascertain specific climate change risks, conditional probabilities, impact costs and adaptation strategies for those supply chain stages and stakeholders not covered through formal insurance schemes based on the survey/techniques provided/conceptualised/adapted for this thesis. The Certain interest exists in the potential research/apparent willingness of these stakeholders to assist in providing information access/potential to participate in the survey/field research and to clarify risk catastrophe modelling for their sector to further validate possible results. This thesis's unique method addition will be to include banking/insurance representatives as essential Pacific MSC' stakeholders, among others to survey and contact for climate change risks.

Chi Test Derivation for Appendix VII Risks (Justified in Chapter 3)

H_0: The distribution follows the Poisson distribution. **H_1:** It does not follow the Poisson Distribution.

Historical Pacific Climate Change Risk Chronol			n = 115	S = Storm, F = Flood, C = Cyclone, D =Drought, L = Landslide, V = Volcano, E = Earthquake, T = Tsunami, H = heatv						
Yea	No of Risk Events	Observed Values O	λ = μ	P (X)	Expected Val	(O–E)2	Chi Squired Tes	df	χ 2 .050	T < Critical Value
1900		0	0.9304	P(X=0) = 0.3944 P(X=1) = 0.3669 P(X=2) = 0.1707 P(X=3) = 0.0529 P(X=4) = 0.0123 P(X=5) =	1	1	1.9739	3	7.815	Do Not Reject Ho
1901		0	0.9304	P(X=0) = 0.3944 P(X=1) = 0.3669 P(X=2) = 0.1707 P(X=3) = 0.0529 P(X=4) = 0.0123 P(X=5) =	1	1	1.9739	3	7.815	
1902		0	0.9304	P(X=0) = 0.3944 P(X=1) = 0.3669 P(X=2) = 0.1707 P(X=3) = 0.0529 P(X=4) = 0.0123 P(X=5) =	1	1	1.9739	3	7.815	Do Not Reject Ho
1903		0	0.9304	P(X=0) = 0.3944 P(X=1) = 0.3669 P(X=2) = 0.1707 P(X=3) = 0.0529 P(X=4) = 0.0123 P(X=5) =	1	1	1.9739	3	7.815	Do Not Reject Ho
1904	C	1	0.9304	P(X=0) = 0.3944 P(X=1) = 0.3669 P(X=2) = 0.1707 P(X=3) = 0.0529 P(X=4) = 0.0123 P(X=5) =	1	0	1.9739	3	7.815	Do Not Reject Ho

Observed values quite simply are determined from the actual data itself which should be obvious from the columns of data in Appendix VII and the above table example. The number of risk events provides the frequency or observed values –i.e. Cyclone in 1904 provides 1 observed value. The expected value of an average event occurrence not distinguished by type as previously explained arises from the expected/probable value which from future risk data (P(X) for best, expected and worst climate change risk scenarios provided by this candidate for P(X =0 to 5). This is taken over the entire period of the sample of various risk occurrences and generally regardless of risk type or location either ends up being 1 or 3 –either 1 event is expected to happen for countries less exposed such as Cook Islands, Kiribati and Palau or 3 events for Australia and New Zealand, regardless of event type. This is further confirmed by lambda λ = μ which merely represents the average or expected value divided by the total time period –(1900-2015) or 115 years. E.g. as the Cook Islands experience 107 risk events over 115 years –this provides 0.9304. This closely approximates the 1 reflected as the expected value of a climate change risk occurrence in any given year regardless of whether that one event is a flood, cyclone, drought etc. Given the nature of climatic variability, uncertainty and multiple factors it is phenomenally complex to distinguish which specific risk event type it is likely to be with 100% confidence for each type of disaster for the calculation of lambda and its corresponding chi-square computation. –Not even the Intergovernmental Panel on Climate Change has resolved that. However, the data generally indicates expected values are consistently 1 or 3 for event types. Expected frequency values are computed separately for each level of one categorical variable at each level of other categorical variables for P(X)**=** $P(x) = \frac{e^{-\lambda}\lambda^{x}}{x!} \quad for \ \frac{x = 0,1,2}{\lambda > 0}$ (1)

Where P(X) = The probability of X risk events for the given time period

λ = The expected/ mean rate of climate change risk event per unit of time

e = Mathematical constant approximately 2.71828

x = Number of Climate Change Risk Events I.e. Storm (S), Flood (F), Bushfire(B), Cyclone (C), Drought (D), Gale (G), Heatwave (H), Landslide(L), Earthquake (E), Tsunami (T), Volcano (V).

Test statistic. The test statistic is a chi-square random variable (X2) defined by the following equation. $x_c^2 = \sum \frac{(O_i - E_i)^2}{E_i}$

Given the chi test formula = (0-E) values are squared, with the accumulated sum to provide the chi squared test statistic for the overall time series data. Observed values and expected values are simply subtracted and squared to provide an accumulated total. As the expected value consistently = 1 across 115 years –this total is divided by 115. Degrees of freedom. The degrees of freedom (DF) is equal to: DF = (r - 1) * (c - 1) where r is the number of levels for one categorical variable, and c is the number of levels for the other categorical variable. Degrees of freedom generally end up being 3 or 6 depending on the data period used.

The test statistic χ 2 .[050] derives at the 5% significance level as most common although the hypothesis remains unchanged at the 1% significance level, although can be adjusted to a different significance level to provide a consistent answer relative to the degrees of freedom. If the test statistic is greater than the critical value, then the null hypothesis of following the Poisson distribution is not rejected. The data also indicates a trend of an increasing frequency of average risk events over time (although not calculated for specific risk types). Although seldom empirically tested and ascertained for climate change risks across supply chains, ports and shipping for existing research, this implies that climate change risks are consistent with predictions of an increased frequency over time based on IPCC estimates; even without considering future emissions scenarios. Unexpectedly this confirms the graph I devised for chapter 1 which indicated on average, Pacific climate change risks were increasing as significant risks for MSC' stakeholders over time.

As provided in standard textbooks on statistical probability theory and Chapter 3, the Chi Squared test is used when two categorical variables exist from a single population/data sample to test for variable independence to determine whether there is a significant association between the two variables based on the above hypotheses for the Poisson distribution skewed asymptotically to the right. This indicates whether an observed frequency distribution approximates the theoretical Poisson distribution with V degrees of freedom is the probability distribution of the sum of the squares of independent standard normal variables. Correlation can infer a trend even if not causality. The test results further validate the Poisson distribution across not just the Cook Islands but other Pacific nation examples, based on time series data across risks. The longer the data interval, the larger the probability with discrete rather than continuous random variable values. The distribution can also link to determining the conditional probability of a maritime supply chain asset failure from a specific climate change risk event for KRQA. As explained previously in person, in submitted chapter draft and risk method notes, this Poisson distribution is utilised for several reasons given the time series data satisfies Chapter 3 outlined, Poisson distribution assumptions.

Chapter 3 previously indicated the validity of the Poisson over the normality, binomial and other distributions. The normality distribution ignores significant increases in trends as potential results. Climate change risks assume that outliers in time will become more frequent. Based on assumptions of certainty and normally distributed population data, randomly selected do not apply to climate change events with multiple variable parameters of uncertainty about the frequency of specific risk event types in a given year, even if the trend indicates increased frequencies/probabilities of risk events. –i.e. 1 in 2000, 3 in 2001, 3 in 2005 but 0 in 2009 and 4 in 2010 14 for 2000-2010 for the Cook Islands had, yet there were only 4 events per decade for the 1920's. Standard deviation does not apply, as a number merely scalable to Gaussian bell curves given significant deviations can occur in any particular time period, location and risk event type. The time series data and derived equations does not reflect normal distributed data assumptions but reality which incorporates scalable randomness in addition. The equations can be modified but can derive to reflect data. Finally, even Monte Carlo methods based on theoretical risk simulations rely on the Poisson distribution assumptions –One advantage of this research is that it is the first to provide a centralised database of 1900-2015 for all Pacific climate-related risk events/types across 17 Pacific locations and seeks to use theory to validate reality not reality to validate theory being flexible considering climate change risk as dynamic not just static.

This method proposes impact costs can be calculated and adjusted from equation 4 and summarised for each stakeholder based on past, current and future risk events. Probabilities of events can be multiplied by duration and frequency then multiplied by accumulated impact costs ($P(x_i.fr.d)$) This calculates a supply chain's, future, economic impact costs for a specific commodity in equation 3.11. Assuming an event's probability as 1 if present/previously occurring and 0 if not; the probability of an event occurring, multiplied by average event frequency, multiplied by average duration (in days), multiplied by actual intensity/impact cost calculated, provides an indication of present and future event, impact costs. The model focuses on event specific, disruption costs, in determining coefficient estimates to be included over time. It can incorporate panel data specifically applicable to other Pacific, supply chain locations, stakeholders, stages, impact costs and/or additional risk events. It can be restricted to direct, indirect and/or intangible impact costs for stakeholders. Being fixed these costs are stabilised for potential rates of depreciation, inflation and exchange rate fluctuation. Costs are calculated in US currency values. This is considered the most accepted, exchanged international currency and one for which information is internationally consistently available.

Future Climate Change Risk Impact Costs for a Pacific MSC (FCCREIC).

$$C_0 + P(x_i.fr.d)\ \Sigma\,(B - TC)\ (y_{j1}\Delta t + y_{j2}\Delta t\ y_{j1} + y_{j3}\Delta t + y_{j4}\Delta t + y_{j5}\Delta t + y_{j6}\Delta t + y_{j7}\Delta t + y_{j8}\Delta t + y_{j9}\Delta t + y_{j10}\Delta t + y_{j1}\Delta t + y_{j11}\Delta t + y_{j12}\Delta t + y_{j13}\Delta t + y_{j14}\Delta t + y_{j15}\Delta t + y_{j16}\Delta t + y_{j17}\Delta t + y_{j18}\Delta t + y_{j19}\Delta t + y_{j20}\Delta t + y_{j21}\Delta t + y_{j22}\Delta t + y_{j23}\Delta t + y_{j24}\Delta t + y_{j25}\Delta t + y_{j26}\Delta t + y_{j27}\Delta t + y_{jn}\Delta t) + Et.$$

(Equation 2)

Where: Let fr = frequency, d = event duration.

To address KRQB, climate change impact costs for MSCS are calculated by summarising the above **HCCREIC/FCCREIC** costs for Total costs (TC) as in section 3.4.

$$TC = \sum P(y_j x_i . c_{ij} .)$$

(Equation 6)

Substitute with Bayes Theorem $P\left(y_j x_i\right) = \frac{P\,(x|y)P(y)}{(P x_i|y_{j1})+(x_i 1 y_{j2})+(x_i 1 y_{jn} C_{\cdot ij} \dots)}$.

$$TC = \sum \frac{P\,(x|y)P(y)}{(P(x_i|y_{j1})+(x_i 1 y_{j2})+(x_i 1 y_{j3} \dots C_{\cdot ij} .))} C_{\cdot ij} .$$

(Equation 7)

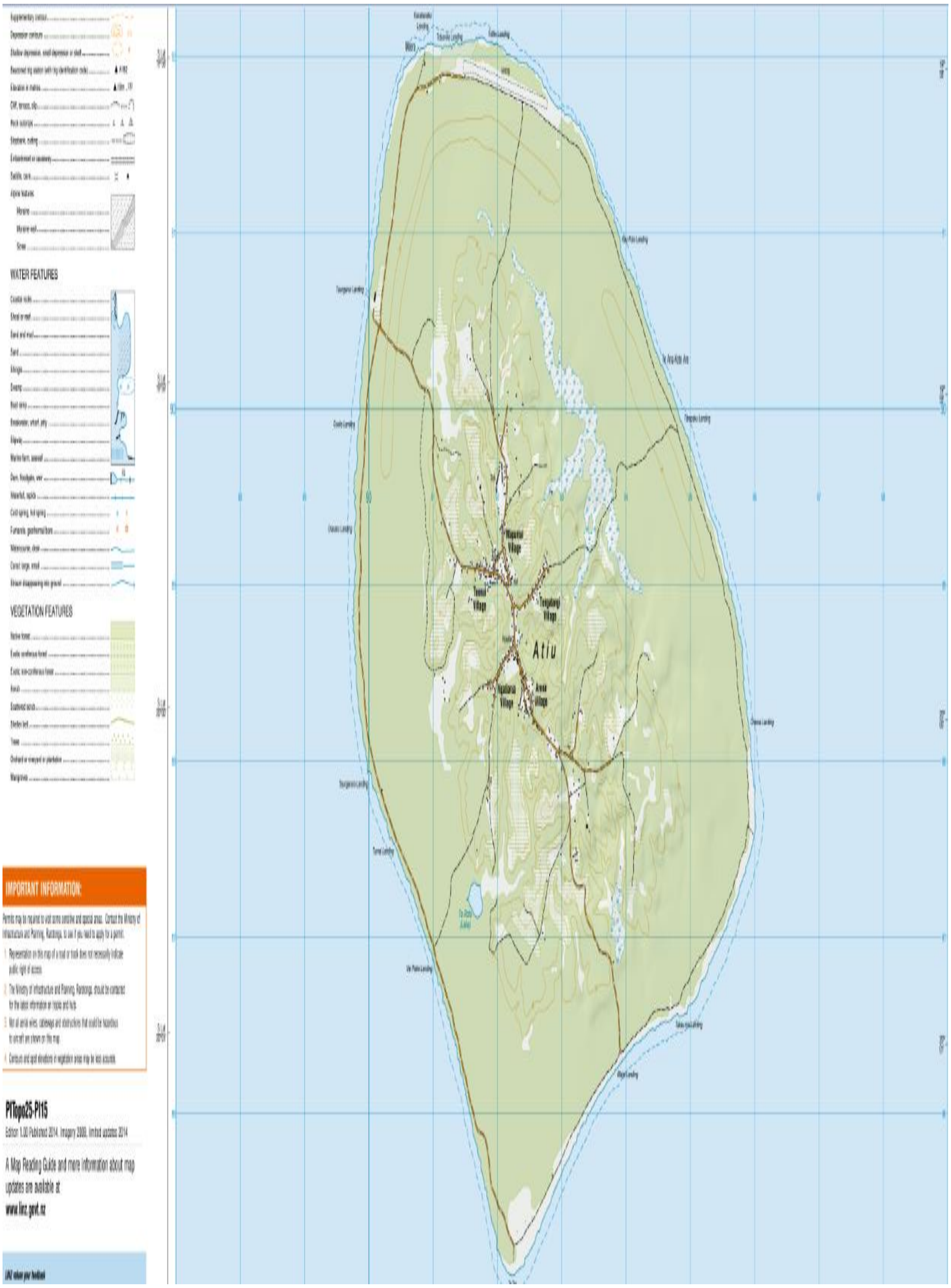
This thesis proposes lifecycle asset replacement cost includes fixed asset, lifecycle values based on long-term risks i.e. SLR, precipitation, ocean acidification and temperature changes. These affect an asset's exposure to climate change over a significant time horizon. This measures risk over an asset's projected lifetime and discounted for years. Fixed asset, lifecycle value = net present value at time built, as initial cost. Risks associated with climate change uncertainty can be resolved through discounting into subsequent, future time periods, testing for autocorrelation. This assumes accepting the probability of occurrence as high enough to be certain over various proposed time horizons, based on Pacific, Climate Change Projections in Chapter 4. Each supply chain stage can be aggregated to provide a specific event's, total economic impact and discounted over future periods. As a possible, future research area, this approach could calculate indirect, impact costs of specific risk events.

Appendix X: Cook Islands Topographic Maps (Land Information New Zealand 2016)

These maps are included to emphasise, supply chain, case study vulnerability to physical climate change risks (Chapter 5)

Aitutaki

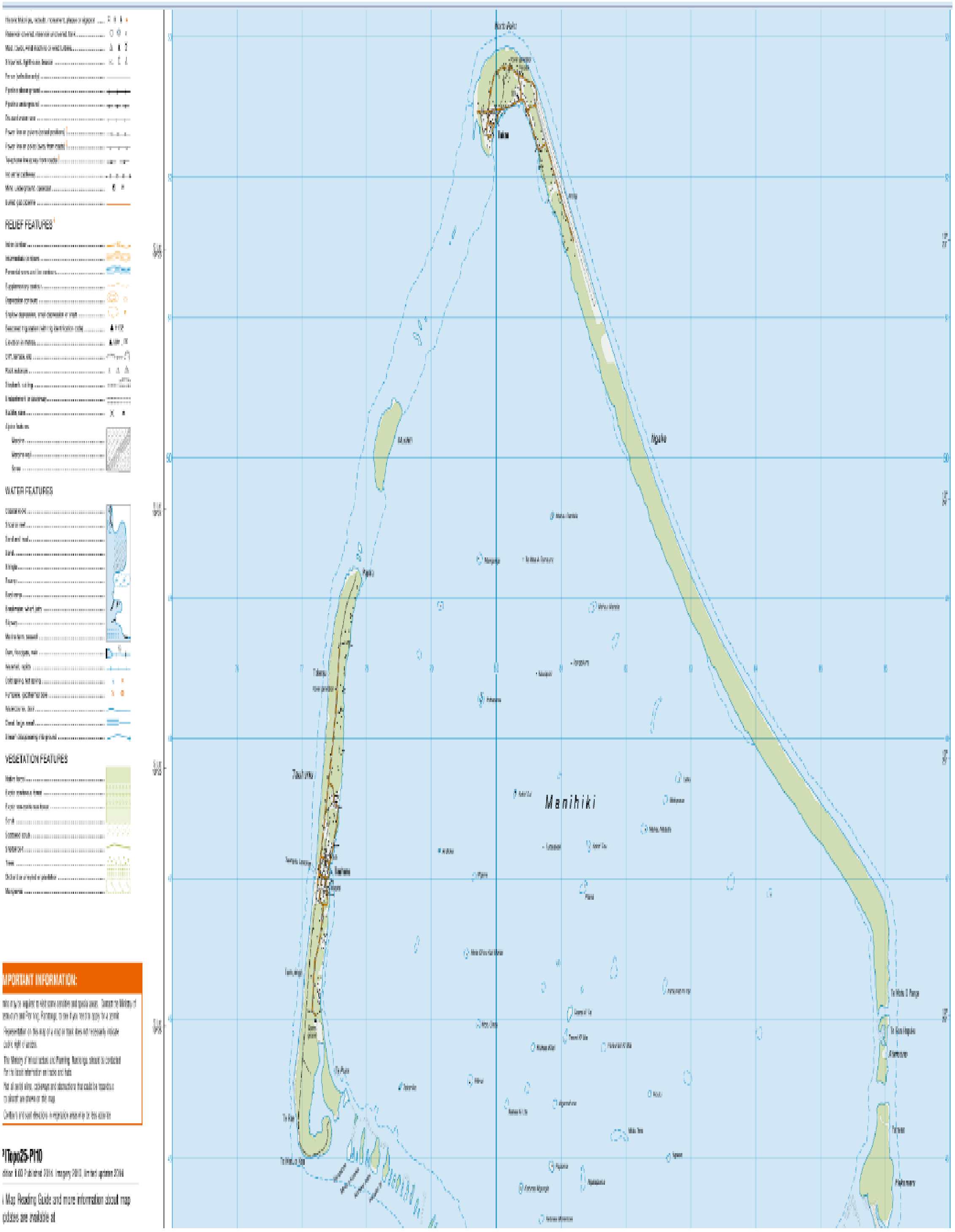
ATIU


WATER FEATURES
VEGETATION FEATURES
IMPORTANT INFORMATION:
PITopo25-PI15
A Map Reading Guide and more information about map updates are available at
www.linz.govt.nz
Atiu

MANGAIA


RELIEF FEATURES
WATER FEATURES
VEGETATION FEATURES
Mangaia
Tamarua Village

MANIHIKI


RELIEF FEATURES
WATER FEATURES
VEGETATION FEATURES
IMPORTANT INFORMATION:
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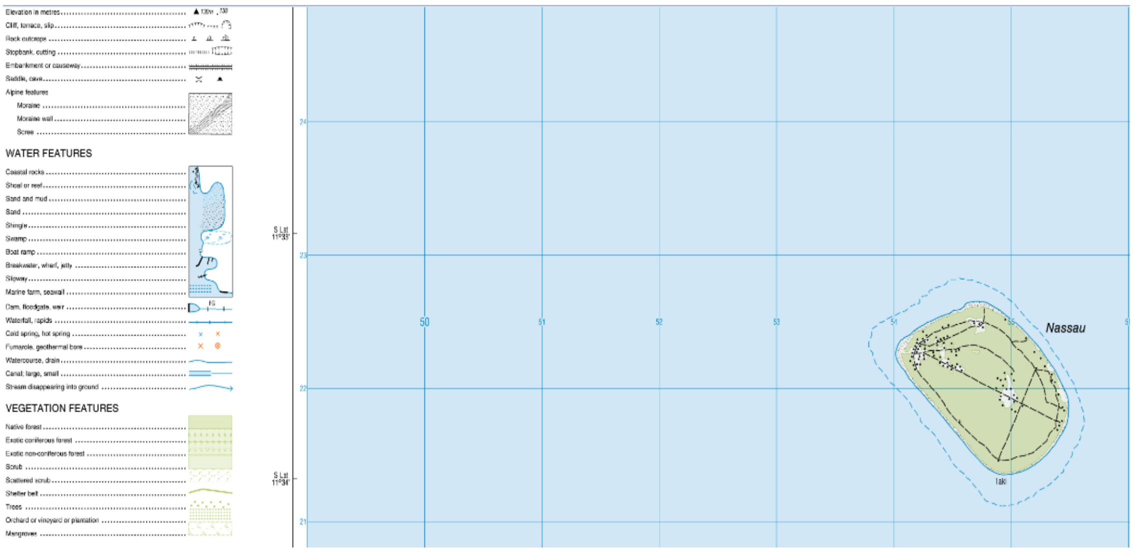
Tauhunu
Tukao

MANUAE

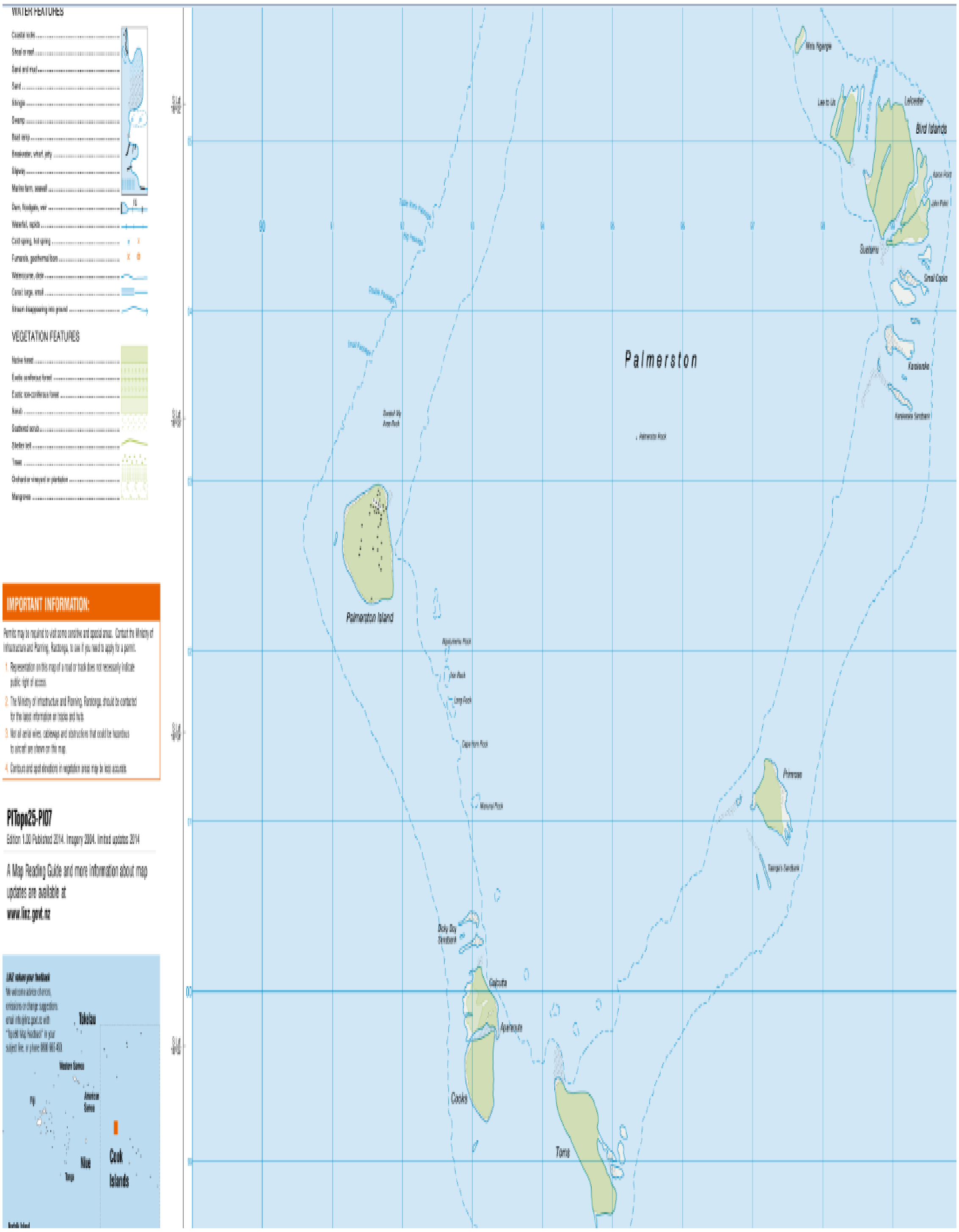
MAUKE

MITIARO

NASSAU

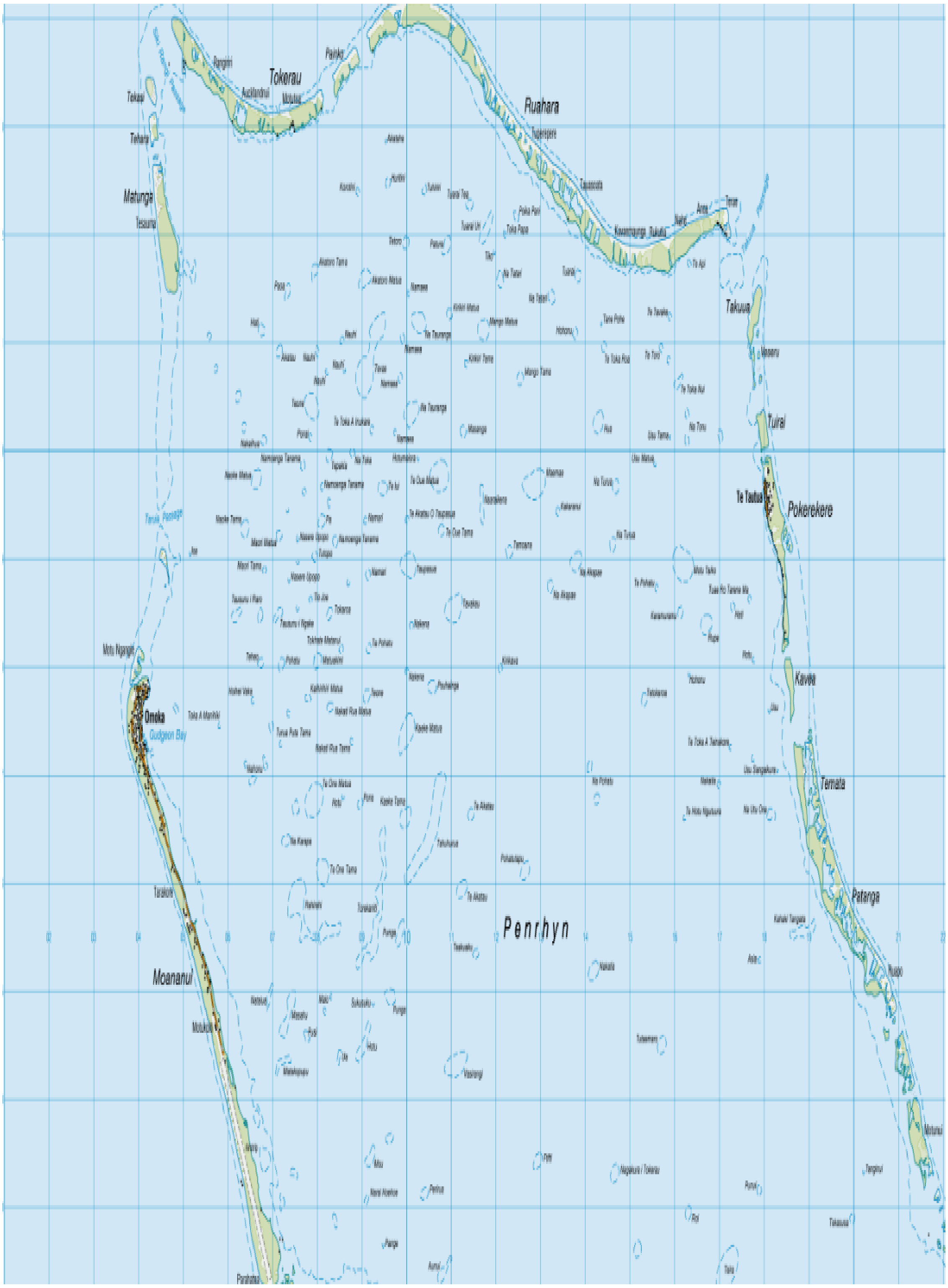


PALMERSTON



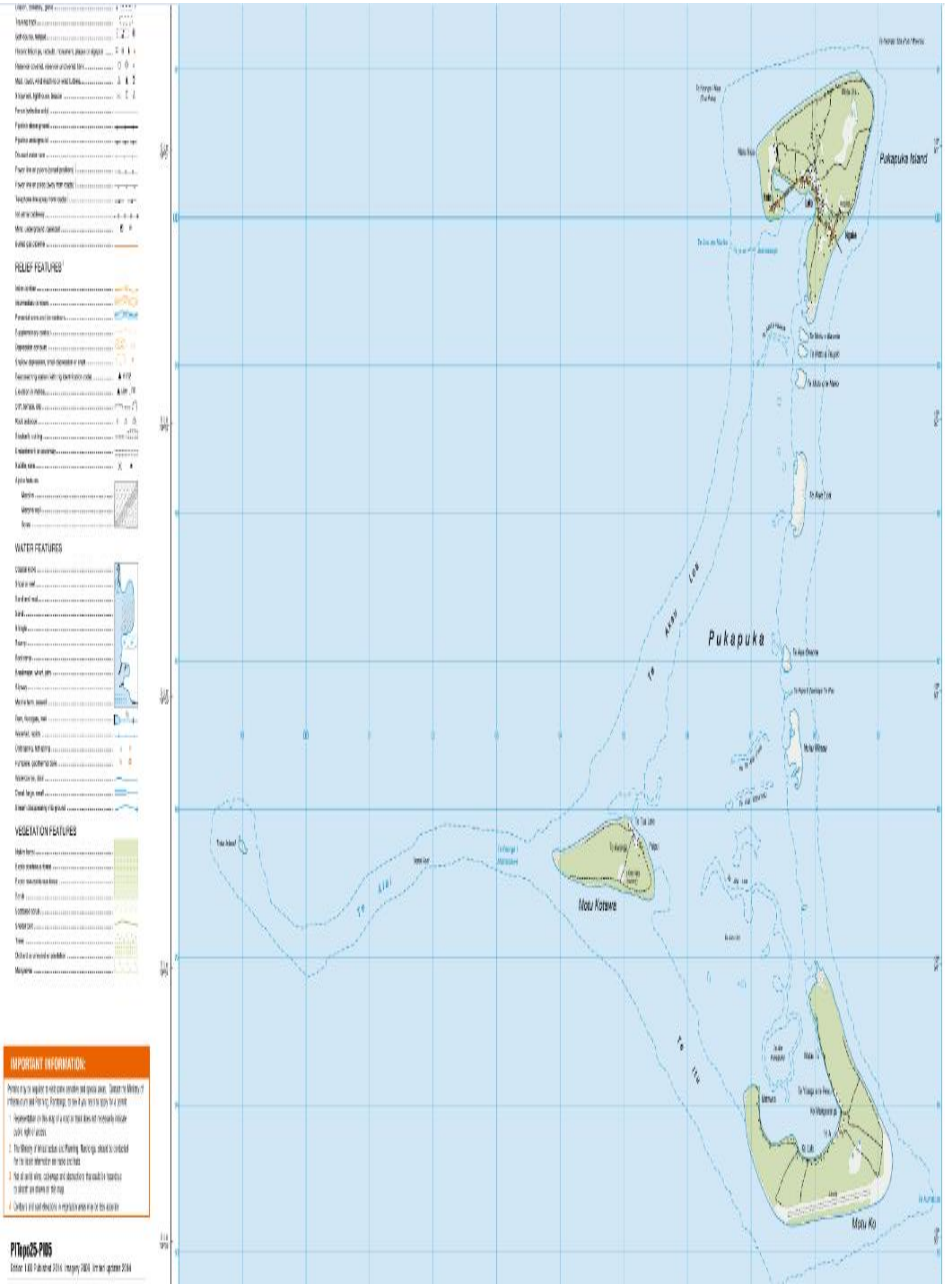
WATER FEATURES
VEGETATION FEATURES
IMPORTANT INFORMATION:
PITopo25-PI07
A Map Reading Guide and more information about map updates are available at
www.linz.govt.nz
Tokelau
Niue
Cook Islands
Palmerston
Palmerston Island
Bird Islands
Leicester
Primrose
Cooks
Toms

PENRHYN



Tokerau
Ruahara
Matunga
Takuua
Turai
Te Tautua
Pokerekere
Omoka
Gudgeon Bay
Kavea
Temata
Patanga
Penrhyn
Moananui

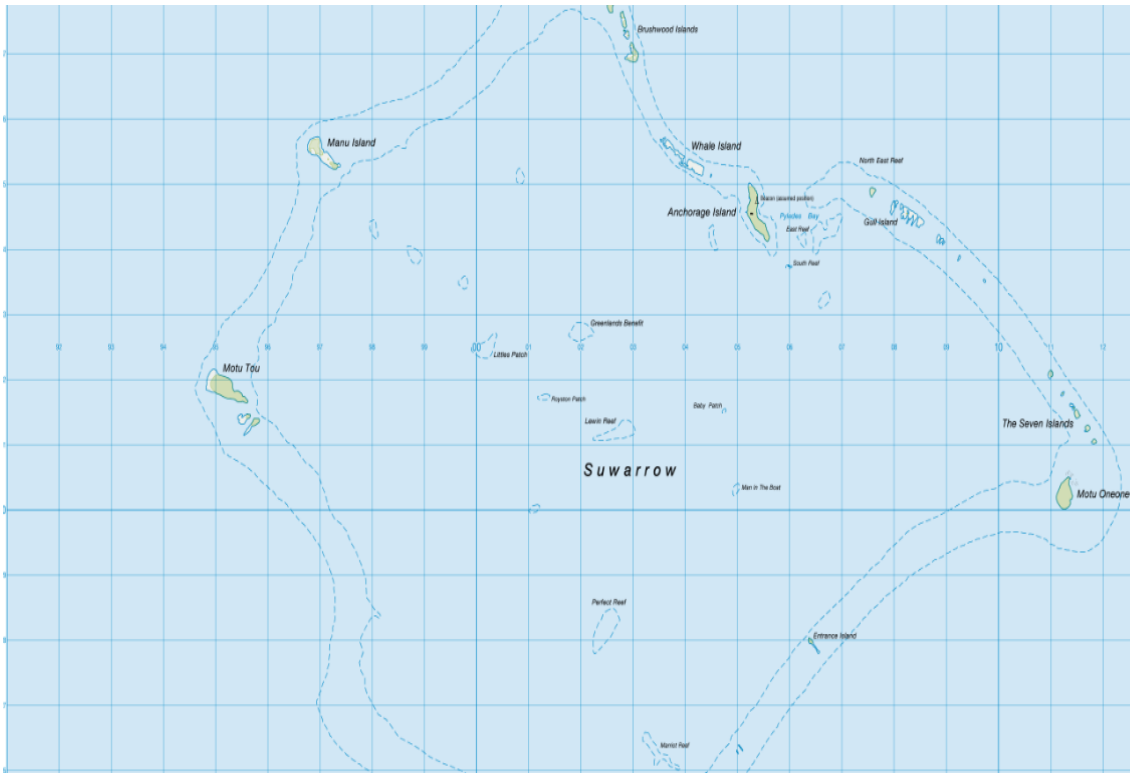
PUKAPUKA



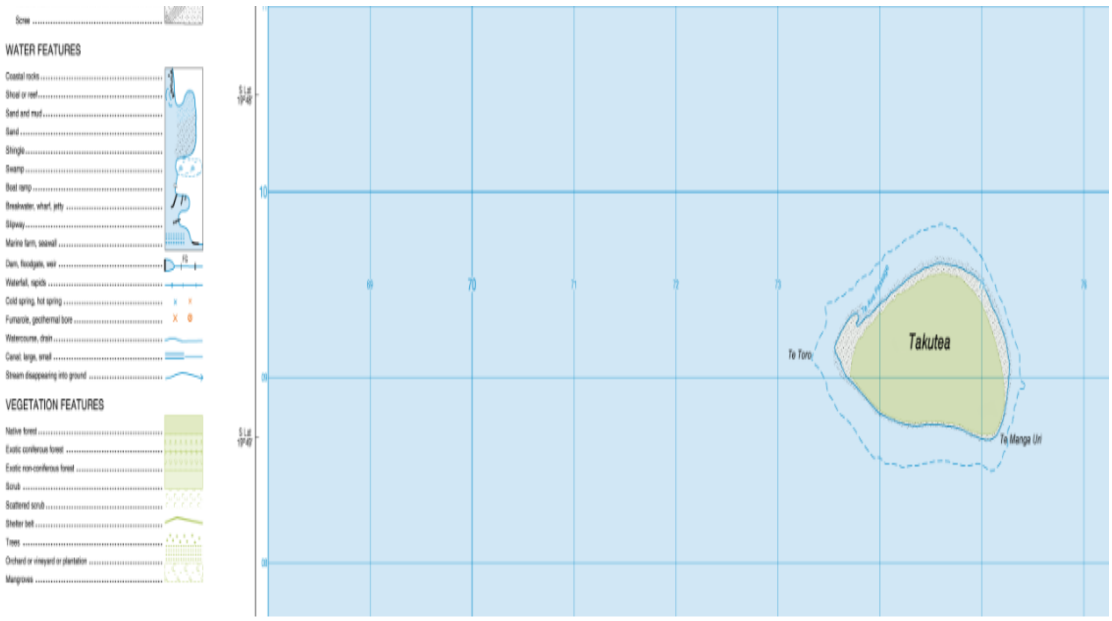
RELIEF FEATURES
WATER FEATURES
VEGETATION FEATURES
IMPORTANT INFORMATION:
PITopo25-PI05
Pukapuka Island
Pukapuka
Motu Kotawa
Motu Ko

RAROTONGA

SUWARROW



TAKUTEA



Appendix XI: Pacific Climateproofing Adaptation Strategies

Image (MSC Stage)	Adaptation Project Initiated/ Status?	Pacific Location	Funding Source/Reference
Marine Resources/Ecosystem	Coral Triangle Initiative, Biodiversity, Conservation	All –Fiji, Palau, Tuvalu	
Producer	Community Fishing –Partial, Commercial -No	Fiji, Samoa, Kiribati, Tonga	SPC 2015
Value Adding/Industry	Aquaculture –SPC,	FSM, Marshall Islands	2011-2015, SPC 2015
Seaports	Climate Smart Seaports; Pohnpei Port, Cook Islands	Fiji, Papua New Guinea, FSM	ADB 2014
Shipping	None	All	Field Research
Roads, Transport, Logistics,	Kosrae/Samoa Roads, PNG Airfield, None Private Sector	FSM, Samoa, Papua New Guinea	ADB 2014
Customs	None	All	Field Research
Import, Export, Transhipment	None	All	Field Research
Wholesaler, Retailer	None	All	Field Research
Fuel, Utilities	Fuel –No, Renewable Energy, Water -Yes, Sanitation/Waste –Yes	Tuvalu, Vanuatu	USP 2013, SPC 2015, SPREP 2015
Information/Communication	-Partially NAPA's, Telecommunications, Media –No, Information uncoordinated/sporadic	All	Australia Bureau of Meteorology 2014
Marketing/Administration	None	All	Field Research
Consumer	None	All	Field Research/Literature Review
Financial/Insurance	None Financial, Insurance –PCARFI Implemented	All	PCARFI 2015
Entire Pacific MSC	None	All except Australia (seafood)	Field Research/Literature Review
Other Supply Chains/ Economy	Agriculture, Forestry, Tourism, Community -Partial	All –Samoa	See Table XI: b below

Table XI(b): SUMMARY OF OTHER CLIMATE CHANGE PROJECTS FOR SOUTH PACFIC ECONOMIES

Project Title	Project Type	Pacific Location	Period/Reference
ACCIPIR, AusAid	Agriculture	All	2011=2015
Climate Change Vulnerability Assessment	Information	Solomon Islands	2011-2014, Rodill 2014
CCCPIR	Coastal Protection	Tuvalu	SPC 2015
CSIRO Centre for Bushfires and Natural Hazards	Information, Education, Research	Australia	SPC 2015

Drought Resilient Crops and Farming Systems	Agriculture,	PNG	SPC 2013
Global Climate Change Alliance Projects	Agriculture, Education, Health		SPC 2015
National Adaptation Plans of Action	Various –Mitigation, Adaptation, Relocation	All	2005-2015
National Disaster Management Plan	Risk Response/Preparation	All	2005-2012
National Flood Risk Information System	Risk Information	Australia	
National Policy Strategy and Institutional Framework for Resilient Agriculture	Agriculture	Palau	SPC 2015
National Strategic Programmes for Climate Resilience	Various –Coastal Protection, Public Infrastructure, Communities	Most	SPC 2015
NCCARF	Information, Education, Research	Australia	
PACC Programme	Agriculture	Most	2011-2015, SPC 2015
PACCSAP Project	Information/Risk Awareness		2008-2014
Pacific Islands Climate Prediction Programme	Information	Most	SPREP 2015, 2004-present
Pacific Disaster Net.	Information		Pacific Disaster Net
Pacific Islands Disaster Assist Programme	Risk Recovery	Most	SPREP 2015
Pacific Risk Information System	Information		SPREP 2015
Port Vila Urban Development Project	Municipal,	Vanuatu	ADB 2013
Rainfall and Runoff Standards	Information	Australia	SPREP 2015
Reforestation, Rehabilitation and Community Forestry Resilience Project	Forestry/Bushfires	Samoa	
Resilient Atoll Agriculture	Agriculture	Solomon Islands	2011-2015
SOPAC Tsunami Plans	Information	Most	SOPAC 2011
South Pacific Sea Level and Climate Monitoring Programme	Information	All	Australia Bureau of Meteorology 2016, 1991-2011
Sustainable Community Development Programme	Risk Economic Recovery	Samoa	UNDP 2015
Sustainable Tourism Adaptation	Tourism	Samoa	SPREP 2015
SPC–GIZ and SPREP Project	agriculture, communication, ICZM, DRM, energy, education, fisheries, forests, health, IT training, land use, relocation, tourism	Various	2012-2016.

Tuvalu Ridge to Reef Project

MSC Ecosystem Stage: Tuvalu Ridge to Reef Project

Tuvalu's GEF, Ridge to Reef Project provides a case study for marine ecosystem/resource stage adaptation (GEF 2016). Its objective involves communities targeting climate change adaptation through investing in integrated water, land and coastal management of natural resources. This is prioritised into the Tuvalu, National Adaptation Plan of Action goal. '*To develop and strengthen community based, conservation programmes on highly vulnerable, coastal marine ecosystems.'* The project's physical output achieved a 2009 Marine Biodiversity Plan and GIS database; extending marine protected areas by 15%, towards restoring the ecosystem. A Marine Life Project identified existing marine resource condition (Job 2009). It added legislation, sustainable land use and stakeholder consultation through workshops. Projected adaptation costs were initially funded $636,000 by Tuvalu's government (Table XII(c)). For future phases, $19,443,435 is estimated but not specifically allocated (UNDP 2015).

Table XII(c): Tuvalu Marine Ecosystem/Resource Adaptation to Climate Change Risks

Activities (2012-2014)	Year 1	Year 2	Year 3
Develop a sustainable, community based, management plan for coastal marine biodiversity	$20,000	$15,000	$15,000
Identify and implement priority conservation areas	$130,000	$130,000	$125,000
Develop a community marine resources inventory	$60,000	$30,000	$20,000
Integrate traditional and modern conservation practises			$20,000
Community Awareness and Capacity Building	$15,000	$40,000	$15,000
Contingencies	$500	$500	$500
Sub Total	$225,500	$215,500	$195,500

Source: Government of Tuvalu 2011

From a MSC' perspective, this project offers several advantages when critically evaluated from Figure 3.4 criteria. As the Pacific, Ecological Capital Theory of Risk Management proposes; preserving and restoring natural resources enables stakeholders to retain productive efficiency after a risk event. It enables a return to business as usual, retaining supply chain performance, as coral reef restoration and habitat protection eventually allow resources to grow. In contrast, existing developed world, adaptation studies can be criticised in focusing only on people and physical infrastructure assets. Recovering from risks becomes only temporary; marginalising multiple, economic values of natural ecosystems and ignoring resource security (Table 5.2). Given constraints of Pacific nations and many commercial stakeholders; natural ecosystem projects such as Ridge to Reef are technically feasible; requiring limited capital, technology and skilled labour investment, compared to hard engineering, adaptation solutions. It retains supply chain competitiveness. Any temporary loss after a risk event is overcome by greater co-benefits of increased resource access, more environmentally sustainable.

Commercial producers, industry and other stakeholders can out-compete those businesses ignoring long term, global uncertainty over ecosystem resources. Tuvalu protects biodiversity through education, a Biodiversity Action Plan (Tilling and Fihaki 2009), reserves and legislation. Providing greater information over asset condition and ensuring asset protection enables more optimal allocations of resources and operational planning. It satisfies many stakeholder requirements including being profitable in the long run; minimising future disruption and inventory costs and ensuring supply is able to address demand. This project also concentrates on reducing the extent of ecosystem risk through replacing vegetation and mitigating emissions. Ridge to Reef provides advantages of reducing physical vulnerability to risk and increasing coastal resilience. Ensuring reserves where marine ecosystems can recover; ensures stakeholders possess options of future flexibility and enhanced adaptive capacity among communities and businesses. Other global supply chain stakeholders ignoring marine resources cannot secure this. It reduces maladaptation costs where existing seawalls and hard engineering, coastal protection measures accelerated erosion, habitat loss and pukka crop salinity. Given risk projections indicate significant ecosystem collapses without investment; Tuvalu and other Pacific approaches enable risks to be monitored, impact costs minimised and with greater, more certain resources to recover; than many of the developed world.

However, Tuvalu's Ridge to Reef and other natural ecosystem, adaptation strategies possess disadvantages from a MSC', commercial perspective. These require a significant amount of time to become effective. Yet businesses have to survive in the short and medium run. Additionally, answers require funding. $636,000 ignores the net marine ecosystem value preserved, the costs/potential revenue for business and projected rates of return on investment, versus the opportunity cost of other adaptation efforts or inaction costs. Ridge to Reef violates the equity or user pays principle, (as customers, local or international businesses who benefit from resource security don't pay). Proposing a legislative framework and community approaches are insufficient without including commercial stakeholders. Pacific adaptation constraints of limited enforcement capacity have not been addressed. Therefore, other MSC stakeholders and stages have limited incentive to conserve resources or invest in risk reduction/adaptation. The degree to which it specifically lowers risk isn't calculated. These specific measures concentrate on marine resource restoration but are ultimately not ecologically sustainable, as this approach does not reduce resource exposure to increasing ocean acidification, cyclones and other risks. As Chapter 7 indicates, for climateproofing adaptation to be truly effective, Tuvalu needs to invest in ecological reef rehabilitation similar to Fiji, to ensure stakeholders and ecosystems can survive across risk types, scenarios, stages and time horizons.

Coral Reef Restoration for the South Pacific

Since 2002, 17 Pacific nations have partnered with the French Development Agency, focusing on coral reef restoration and community, climate change adaptation. This thesis recognising the significance of coral reefs to marine resource and MSC' economic activity in Chapters 5/7; critically evaluates a 2006 pilot project in Korolevu, Fiji (Reef Explorer 2017). Its project objectives included assessing marine assets and biodiversity vulnerability to risks. It considers sustainable economic and ecotourism usage, promoting information awareness and community resource management/governance. Species catch size was controlled. Traditional bans preserve existing reefs further. It also aims at adapting reefs by monitoring, growth and transporting corals. Marine management plans and economic conservation incentives were initiated with stakeholder consultation. Over 14,000 corals from 25 species have been nursery grown and transplanted, enhancing the limited reef area and species biomass by approximately 500% to 2016. It produced 50 % biodiversity increase with evident ecological sustainability; compared to conventional resource extractive, methods of risk management; presuming resources will exist to restore business as usual conditions. One fundamental study limitation is that no adaptation costs are provided. Funding is obtained from multiple governments, NGO's and other sources, enticed by publicised successes. There is no indication of how this is viably sustained, without commercial involvement and how it can be extended across the entire coast. However, the local coral reef ecosystem is estimated as worth over $12,000,000 per year in economic activity.

From a MSC, stakeholder perspective, ecological rehabilitation of coral reefs offers further commercial advantages in preserving supply chain, productive efficiency, competitiveness and performance. Valuing these ecosystems ensures ultimate resource security. Biodiversity promotes future commercial opportunities as more species are researched and preserved. Contributing to coral reef protection ensures stakeholders can minimise non-human risk factors anticipated to reduce the quality, volume, value and existence of ecosystem resources. Coral reefs provide coastal protection advantages minimising exposure to cyclones, storms and other risk events. Although the current project focuses more on ecotourism with limited specific relevance to coastal infrastructure; businesses could specifically ensure monitoring and extension of reefs. This reduces individual and systematic vulnerability to risk events and associated impact costs. ADB (2013) and others estimated no hard engineering or adaptation measure have proven as effective at climateproofing transport assets; as reefs. It further enforces the equity principle; where those personally benefitting, contribute whilst possessing every incentive to reduce pollution, favour sustainable development and other co-benefits. Unlike non-ecosystem-based approaches, preserving coral reefs ensures opportunity costs of collapsing reefs/resources don't have to be factored into present or future, supply chain operations.

The project is technically feasible. Provision was made for stakeholder training in monitoring and coral nursery processes. The standardised Reef Base database and access to information via the Global Coral Reef Monitoring Network along with funding, has aided local communities. However, a fundamental weakness includes ignoring MSC stakeholders from aquaculture to ports, shipping, retailers and consumers, so they value coral reefs and adapt. However, selective coral reef restoration possesses significant limits to climate change risk adaptation. Aside from uncertain cost estimates, reefs involve time to develop, which increasing risk events, human and other pressures may undermine. For the Korolevu site, coral reef monitoring was abandoned as early as six and nine months, due to extensive damage to transplanted coral from predators, diseases, methods, uninformed/uninterested people and climate factors. Coral reefs thrive between 25-29º. Given the extent of Pacific and global risk and vulnerable areas, significant resource, species and physical constraints hinder complete adaptive capacity. To ultimately prevail, MSC stakeholders would need to significantly reduce risks of increased, sea surface temperature, ocean acidification and land pressures. Stakeholders would need to globally cooperate on information sharing and risk reduction with the specific short-term, economic benefits outlined.

MSC Producer Stage: Land to Sea Approach Palau

Palau's Land to Sea Approach presents a climate change adaptation, case study for MSC' producers including fishing-based communities and dependent stakeholders (Ngiraingas 2014; PACC 2017). Its objectives concentrate on ensuring food security and income resilience through adapting lowland taro production, upland agroforestry, aquaculture and food processing. Project achievements have produced saline resistant crops, a clam hatchery and a mangrove crab hatchery. This increased species numbers by over 400,000 when released into the sea in 2013. It has enhanced community awareness of risks, legislation and training. Project adaptation costs were $50,000 for supplies, $10,000 for equipment and $15,000 for education and community outreach. This project proved to be commercially viable in producing stakeholder revenue of $3-20 per kg, given high market demand and high scarcity of resources. However, as with most ecosystem-based approaches; this method hasn't evaluated the full extent of commercial costs versus profit, revenue and market opportunities, either in the short or long-run time horizon. It hasn't calculated costs of alternatives versus costs of ecosystem losses/collapses or inaction.

Investing in local ecosystems and communities through income diversification and security; ensures MSC stakeholders retain the capacity to survive and remain economically active, despite increasing risk. Investing in sustainable fisheries management and commercial species, testifies substituting responsible ecological capital investments can be more economically profitable than existing, extractive techniques. This includes releasing certain species into the wild to boost natural stocks. It remains cost effective requiring minimal inputs, despite economies of scale and low profit margin constraints. This approach retains supply chain productive efficiency, competitiveness and performance. Enterprises remain commercially viable through access to sheltered, controlled species after a risk event; given potential damage to vessels, ports and coastal infrastructure/services. It is ecologically sustainable and flexible being adaptable across markets, risk types, species, markets and stakeholders as potentially renewable resources. This secures present and future adaptive capacity more effectively than uncertain wild supplies. Greater import substation enhances local resilience to increasingly globalised risk, creating higher disruption costs. Considering local agriculture ensures stakeholders preserve greater disposable income to benefit other supply chain stages. It extends local and regional markets; facilitating commercial opportunities to offset international disruptions to customers.

Palau's approach also promotes equity. Stakeholders directly contribute towards the survival and health of species such as mangrove crabs; providing an alternative supply source. It potentially minimises maladaptation costs that may develop for artificial breakwaters and seawalls. This further enables businesses to benefit from increased publicity/lower costs, whilst simultaneously lowering opportunity costs against uncertain risks. Extensive research indicates these methods are technically feasible given existing constraints, not just for the Pacific but in Africa, the Caribbean and developed nations. However, disadvantages include being challenged to adjust species, techniques and businesses to more frequent risk events of greater duration, frequency and intensity. Commercial stakeholders lack information, awareness, access to funding capital, private insurance, land, and other adaptation constraints. These remain problematic, especially internationally based operators unfamiliar with localised conditions. As a species, crabs are highly vulnerable to bacteria, local water, soil and mangrove quality. Limited ecologist, geneticist and skilled aquaculture personnel/technology exist. It also poses risks to reef preservation and rehabilitation. Palau's limited species number and community enforced bans for conservation, ensure limited exporting opportunities currently exist; subservient to domestic market and tourist requirements. The 2017 Palau Crab Bank project is currently restricted to only 50 under controlled conditions, despite a market price of $100 per kg paid to local communities.

Kiribati Community Based Fisheries Programme

The Pacific provides several case studies emphasising risk adaptation for MSC' producers. This answers ARQII/KRQC. The Kiribati, Community Based, Fisheries Management Project involved five communities on Butiari and North Tarawa from May 2014. Its project output included stakeholder consultation via workshops, creating marine reserves, legislation and community resource management plans. These plans voluntarily agreed to by businesses included banning damaging fishing gear and fishing practices, harvesting undersized species, destroying coral and spawning species. They included scaring fish via metal bars, net and harvest limits. Coral pools are protected. A further meeting arranged for future experiences learnt.

Legislation was drafted so t communities could enforce protection of their commercial and ecological futures, from outsiders. The 2013-2025 National Fisheries Policy specifically highlights climate change risks for tuna species, coral reefs and coastal infrastructure (Kiribati Ministry of Fisheries and Marine Resources 2013). To adapt, aquaculture projects have been introduced along with species monitoring and training. Kiribati has implemented a practical 'cap and trade' fisheries management scheme: This limits industrial, tuna fisheries to conserve stocks of skipjack, yellowfin and bigeye tuna at levels that should ensure sustainable future benefits. It allows greater harvesting under a vessel day scheme, during more abundant periods. Greater species monitoring and harvest controls via fish aggregating devices is favoured based on catches versus surveyed population. Producers can exchange days from each other. The programme extends wharfs, local business incentives and improved services, encouraging businesses to remain at more climate resilient and aware, marine producer facilities. More facilities exist to smoke and dry fish for longer.

To determine the extent to which climate change adaptation is commercially profitable for MSC stakeholders, the above programme cost $530,000. This was funded by SPC (SPC 2013) and other stakeholders in the absent of private sector investors. The net worth of commercial fisheries was $34,000,000 for 37,000 tons. However, the projected rate of return on investment is calculated as potentially worth a market price of $2481.75 per ton. 214 tons would need to be produced to recover investments. The opportunity cost of inaction is at least a 15-35% decline in wild fisheries populations and equivalent revenue. These values also ignore ecosystem value. It includes related declines in supply chain activity across all economic sectors. This climateproofing adaptation strategy therefore satisfies Figure 3.4 criteria to address commercial stakeholder requirements. Community involvement, resource procurement and cooperation minimise input costs, risks to resources and associated disruption costs. It ensures markets and profits remain. By securing supply through an ecologically sustainable solution, it enables producers to grant greater certainty to other supply chain stages. Seaports, value adding and other stages therefore experience lower interruptions to cargo throughput, productivity and performance. Businesses can remain competitive compared to those with uninformed stakeholders. This solution contrasts with conventional supply chain risk management, which crucially ignores the need to inform producer stakeholders of associated risks, impact costs and ensuring ecosystems can remain functional.

Existing sources of training, capital, technology transfer and Pacific case studies including Kiribati; ensure that asymmetrical information and other past adaptation constraints are minimised. Community fisheries management programmes are technically feasible and are can be adjusted to other supply chains in agriculture, pharmaceuticals, forestry, mining and others. Their flexibility is adaptable to risk types, locations and stages to extend operational resilience and impact costs. However, the project can be critically evaluated in offering certain disadvantages. In being aid funded by communities it does not provide sufficient cost, revenue and profit information for businesses to determine its commercial viability in the short term. It does not demonstrate how this minimises cost compared to existing ocean extractive production, to convince cooperation. It does not evaluate the opportunity cost of investment. It ignores potential maladaptation costs. This solution ignores the equity or user pays principle as it completely ignores the need to integrate international MSC producers/other stages in information, communication and law enforcement. The approach completely ignores any indication of how this will affect the time and cost it would take for ecosystems to recover. Long term risks may be monitored but remain unresolved as does the increased duration, frequency and intensity of risk events. In response, this solution proposes the above concerns are addressed for more effective climateproofing in future research. As previously discussed, effective adaptation requires Kiribati to involve all stakeholders in existing efforts to focus on ecological rehabilitation not just restoration. It needs to monitor and secure adaptation projects against emergent risks and ensure species/people actually adapt under various conditions.

FSM Income Diversification via Mariculture Adaptation to Climate Change

The Federated States of Micronesia, SPC and the Pohnpei Marine and Environmental Institute provide a value adding/industry stage case study for businesses to prosper from climate change risks (Buncle 2013). In facilitating ecological restoration of wild fisheries, it recognises aquaculture can secure and diversify income; which this thesis proposes as an adaptation strategy for MSC' stakeholders. The project's objectives created pilot projects for sponge farms, marine ornamentals, pearl farming and clam mariculture, including 34 fish farmers. Its aims included developing more climate resilient species/habitats, improving monitoring techniques and creating profitable enterprises for those prepared to respond to climate change as commercial opportunities. A Kosrae Shoreline Management Plan was also implemented (Ramsay *et al.* 2014). It also focused on institutional training, community outreach and capacity building to minimise existing adaptation constraints to endorsing new techniques and technology. Coastlines, water and species health are observed and evaluated.

To determine the extent to which climate change adaptation is profitable for MSC stakeholders, this project's adaptation cost $343,590 from 2014-2017. However, it was funded by the US Pacific Climate Fund (PACAM) to counter existing market failure. As with other projects, stakeholders lack knowledge of specific, individual project successes, output, profits and revenue to ensure the investment is sustainable given existing Pacific constraints. Training manuals were produced and are Internet accessible (Ellis *et al.* 2009). Sponges have a market price of $12.50. Yet total cost per sponge excluding shipping is only $2.80. Average labour costs per hour are $2.65 and total sponge farm, capital costs per 12,000 are estimated at $519.46 (Ellis 2012). Similar economics apply to other adaptation projects i.e. marine ornamentals with $2.50 per clam cost, $5 price locally and $45 minimum in the USA.

Using Figure 3.4 criteria; to a certain extent, this adaptation project is highly successful from a MSC' stakeholder perspective. It ensures producers and marine industry professionals are able to profit through investing in aquaculture, addressing stakeholder requirements; whilst minimising costs. This ensures business as usual, so that others are able to retain competitiveness, product and market access at minimal disruption costs and performance losses after a risk event. It preserves performance and productive efficiency. Selective breeding aims to minimise long-term risks from SST, ocean acidification, biodiversity loss, changes in sedimentation, species extinction and SLR. Aquacultural stakeholders may retain a greater competitive advantage at influencing supply, species quality and environmental conditions. Requiring few inputs, the project is technically feasible for businesses to adapt. Aquaculture is both immediately profitable; yet flexible to changing ecological, human, climate risk, scenario, time horizon and stakeholder conditions in contrast to inaction costs. It enhances resilience and adaptive capacity. It increases the value of preserving existing ecosystems to various stakeholders, addressing equity and is more ecologically sustainable than currently overfishing.

However, Pohnpei aquaculture only increases MSC' adaptation to climate change to a certain extent. It currently ignores the need to integrate other stakeholders. It does not effectively resolve the above long-term risks to both wild and mariculture ecosystems, without additional ecological rehabilitation measures. Both the project's ecosystem the local ecosystem value/benefits and need effective estimation. The project's performance still needs to be evaluated over time. Aquaculture itself offers a significant number of risks and disadvantages for MSCs' to consider. Any proposed aquaculture project would need a substantial, environmental impact assessment process. This would need to consider environmental costs to local ecosystems, biodiversity, effluent, chemical emissions, soil pollution, water contamination; habitat loss and other significant externality costs. Aquaculture locations may remain highly vulnerable to projected risks unless this is integrated into planning. Integrated coastal-land use management is necessary. Aquaculture could affect existing fishing/water use activities. Limited land exists and inputs would have to be imported. Limited private sector awareness and capital loan financing currently exist. A higher opportunity cost exists for abandoned projects. For this project to adapt successfully, effective marketing and communication strategies need to target consumers, so demand sufficiently addresses capacity.

Marshall Islands Aquaculture and Fisheries Project

Aquaculture Technologies of the Marshall Islands presents a similar example of adapting Pacific MSC stakeholders through aquaculture (Buncle 2013). Project outcomes included physically surveying and assessing the local marine ecosystem condition and vulnerabilities to projected risks. Over 3 years it established lagoon sites and cages at Majuro and Rongelap; created fish feed and trained local communities to form businesses, reducing dependency on wild resources. The project established a pearl farm at Namdrik Atoll, community managed by its Development Association to increase output from 30000 to 20,000. From Figure 3.4, the extent to which this climate change, adaptation strategy is successful is emphasised in being commercially profitable for MSC stakeholders. The PACAM and USAID funded project cost $1,750,701. In 3 years, 12 sites produced 172.365 tons of fish with a market value of $30,000 to 50,000 per ton or $5,170,950 to 8,612,825. 657.708 tons of fish feed was produced with a market value of $554 per ton or ($364,370.23). This provides fiscal evidence that climateproofing via aquaculture can create commercial opportunities for stakeholders, whilst simultaneously enhancing ecological sustainability on wild marine resources.

This aquaculture example provides similar advantages to Pacific MSC' stakeholders as for the FSM. Significant global market potential exists from establishing a reliable supply of aquaculture related seafood, cosmetics, seaweed, pharmaceuticals, fish oil and fishmeal to address a projected 8.6 billion people by 2033 (UNFAO 2010). Aquaculture aids supply chain stakeholders with greater consistency, quality; reasonable size and comparative price/product supply stability from economies of scale and greater enforcement protection in contrast to overfished wild sectors. This answers stakeholder requirements, whilst preserving productive and allocative efficiency of resources; MSC performance and revenue. Allowing aquaculture would discourage poaching of wild stocks from lower prices and increased supply in competition. It reduces risk exposure to events and marine conditions. As a commercial opportunity, businesses could expand trade and investment potential; in securing biodiversity. It could potentially expand exports, increasing revenue and foreign exchange for other stages. Preserving and extending marketable species improves product market competitiveness for products, which have sufficient economies of scale in production or value.

However, this specific adaptation project at present will not be ultimately successful. There is no indication as to how species will increase in climate-resilience, given projected risk increases. Existing aquaculture projects are situated at lagoon sites, which remain highly susceptible to risk events detailed in Appendix V. Limited land area exists to move inland. There is no indication as to how successful Pacific Islanders with existing constraints, have managed to market their products globally and profitably. The project has not been evaluated previously for its implications on employment and existing MSC' economic activity. This project could possibly violate the equity principle; given there is no transparent account of where PACAM's funding originally occurs. The private, commercial MSC' sector is challenged to compete with community projects including this, backed up by professional aid and training. Sourcing wild species to obtain oil/feed for aquaculture presents high significant costs, with a high bycatch rate, (unless produced without depleting natural sources). Aquaculture can be highly wasteful taking up to 5kg of feed to produce a 1 kg fish. Aquacultural conversion and feed sourcing can also threaten the healthy thriving of aquatic ecosystems, damage coral reefs, seagrass beds and lead to mangrove destruction to establish suitable sites. Cages need frequent maintenance, to prevent litter and decay. A potential health disadvantage to aquaculture includes reduced water quantity/quality with increased nitrates, oxygen concentration/salinity and plant eutrophication. This would harm existing marine ecosystems. For present projects including the Marshall Islands to adapt effectively; aquacultural production needs to be resilient and flexible, to possible changes in seasonal demand.

Finally, there remains a significant risk to potential funders of aquaculture. As with any potential investment decision for scarce fiscal resources, uncertainty remains over whether governments would get a rate of return on their investment as a reasonable risk of bankruptcy exists given a lack of experience/other factors. Pacific, private sector microcredit has focused instead on agriculture. Relying on government funding represents a significant long-term opportunity cost of public taxpayer revenue, not ultimately sustainable. Any potential host site for aquaculture would benefit from a full environmental impact assessment; market feasibility study, cost-benefit, demand –supply analysis; pre and post-event impact. This must be compatible with demand, supply, quality, cost and price; to ensure the most appropriate location of each proposed aquaculture development, its ecosystem/community impact, profitability and productivity. Appropriate funding would need to be secured, sufficient adequate skills development, training granted and resources allocated. This includes a method of enforcement/ administration of justice to ensure compliance with local and international legislation. Other aquaculture projects have failed from a lack of relevant, modernised technology transfer, a lack of information; high coastal property values; limited research, technology, skilled labour, gifted parts and weak extension services

MSC' Seaport Stage: Climate Smart Seaports

Across 17 Pacific nations, currently only Australia and the Cook Islands have prioritised physical climate change risk research and adaptation for seaports. This thesis outlines climateproofing of Cook Islands ports in Chapters 5-7. Scott *et al.* (2013), Chhetri et al. 2013) and Ng *et al.* (2017) offer Australian seaport case studies, (previously assessed in Chapters 2 and 3). This Appendix extension critically appraises its proposed 'Climate Smart Seaport' Tool. Its stated project output created an online tool and research data that Australian and Pacific seaports can evaluate climate change projected risks on seaport activities to aid effective risk management and adaptation. It cited the examples of Fiji and PNG seaports. Its method required users to form solutions using a web user and search database from risk scenarios and datasets. The tool was tested via 2 local stakeholder workshops. It states stakeholders can first establish the port context; then identify current vulnerability and future risks. They can analyse and evaluate risks before identifying adaptation options.

From a MSC', commercial perspective the tool possesses certain advantages in being able to assist with understanding and lowering likely risks, associated impacts and potential solutions. As a qualitative, risk management tool it may increase resilience and lower impact costs to a modest extent. Being an online tool, it represents a cost minimising and effective approach to adaptation for stakeholders, financed by RMIT University. In offering virtual solutions and methods that can be evaluated prior to expensive adaptation, it maximises flexibility, minimising maladaptation and opportunity costs of decisions. Identifying risks and vulnerability can enable effective decision making to ensure users can retain competitiveness, productive efficiency and performance.

Whilst apparently effective as a theoretical tool, this tool can be criticised as of limited value and assistance to Pacific and global MSC' stakeholders. The tool is only mentioned in press releases, RMIT website and sources including Scott *et al.* (2017). It is completely inaccessible to MSC' stakeholders. Neither specific Fiji/PNG case studies nor the tool itself could be physically located and accessed. Even for the sources mentioning it, no specific indication of the costs involved in developing the tool or in obtaining localised data and input variables has been provided. Individual stakeholders still have to physically undertake the expense of a localised risk-vulnerability, impact cost and adaptation strategy, evaluation approach as recommended in this thesis. The tool being qualitative with no empirical impact costs or downscaled projections, is less effective than this thesis proposed method. It includes climate variables but overemphasises stakeholder perceptions of risk using a Likert scale rather than integrating data for risk estimation. The tool does not consider local stakeholder's adaptive capacity and existing constraints to adaptation including the need to secure tool access, institutional capacity and training.

The proposed tool incurs issues of not being technically feasible, as it does not resolve the issue of obtaining scarce data and uploading it. Two stakeholder consultation workshops is insufficient to monitor the value of the tool over time and the extent to which it effectively assists in adaptation based on objective criteria. Criteria could assess performance, competitiveness, productivity and the time, cost or resources taken to recover utilising the tool versus not using it. It also ignores the implications and involvement of other multiple, MSC stakeholders who may affect risk or benefit, violating the equity principle. However, from a commercial perspective the concept of an electronic tool could coordinate MSC and other supply chain stakeholders more effectively in systematic adaptation. The tool needs to be available and reformed to include more case studies and training.

MSC Roads, Transport, Logistics Stage: Climateproofing Kosrae's Roads

Whilst this thesis has located no private transport and logistics stage, sources of climate change adaptation; FSM presents a climateproofing example for Kosrae Roads. Pacific Adaptation to Climate Change completed a 7km road in 2014 for Tafunsuk municipality. This has been physically engineered to maximise climate resilience and reduce physical vulnerability to risk (Buncle 2013). A 2008 king tide previously flooded most of the village, coastline and road. The road was elevated up to 1.5m high to counter sea level rise, storm surge and flooding. It was strengthened from a maximum capacity of 178mm of rainfall per hour to 254 mm per hour. Alternative interior farm roads, culverts and drainage were upgraded. A parallel project concentrated on an Integrated Shoreline Management Plan and community training (Ramsay *et al.* 2014). A tide and rainfall gauge provide an early and local, climate monitoring and warning system. Based on this project and the need to protect core MSC' assets, the FSM government are one of the first and few world governments to pass a law to ensure compulsory climateproofing in infrastructure. The law requires all public and private stakeholders to factor in climate change risk reduction and adaptation, otherwise development permission is not granted.

Based on Figure 3.4 criteria, the above adaptation strategy is cost-effective as a climateproofing, infrastructure investment. The road costs $2,000,000 if not climateproofed and $2,500,000 if climate proofed over a 50 year lifespan (ADB 2014). Average lifetime costs are projected as $4,4,000,000 if risk events do not occur but up to $7.8,000,000 in impact costs for projected risk events but only $5,500,000 if climateproofed. $500,000 saves $2,300,000 excluding opportunity and disruption costs to MSC stakeholders. ADB (2014) estimate the cost of climateproofing new roads at $77,000 per kilometre contrasting with $243,000 per kilometre to retrofit. From a MSC, stakeholder perspective, climateproofing assets ultimately minimises costs and risk exposure as no scenario projects any decline in event frequency, duration and intensity. Financially it created business opportunities for local contractors in climateproofing infrastructure, funded by GEF. If legally compulsory this enable firms to target new markets, products, services, technology, training and other commercial potential. Although roads are often government goods based on public externalities; stakeholders still benefit from climateproofed infrastructure.

They could prosper further by familiarising themselves with the limits of existing climateproofed infrastructure and public-sector investment. They can benefit from technical guidelines and design standards indicating expected risks/costs. This enables more effective adaptation in being aware of localised asset risk exposure, resilience and vulnerability; to modify operations, training and asset locations. Stakeholders can further evaluate asset interdependency. Favouring climateproofed assets enables stakeholders to retain and augment performance, productivity and competitiveness, despite risk uncertainty. Enshrining this as a compulsory decision minimises risks of moral hazard, asymmetrical information, impact, maladaptation and opportunity cost. Despite initially higher costs, it is ultimately more profitable, provides greater probability of an asset's survival and aids long-term decision marking. Utilising simple criteria including asset elevation, training and community participation ensures existing climateproofing adaptation strategies are technically feasible, given existing adaptation constraints. Incorporating shoreline management guarantees localised human and ecosystem pressures do not undermine effective adaptation measures.

However, public sector adaptation including Kosrae Roads are limited in their effectiveness to a certain extent. Based on commercially sensitive or asymmetrical information and other adaptation constraints, comparatively few private sector examples exist for cost-benefit analysis of adaptation. More stakeholders need to be consulted and involved. Commercial stakeholders often lack awareness of where to locate information, which criteria to use and how to ensure short term profitability from climateproofing investments. Limited private sector, financial incentives exist including access to capital. Stakeholders don't know their individual and system, supply chain risks, costs and benefits nor whom ultimately pays for it, violating the equity principle. Smaller businesses may especially be challenged in their fiscal capacity to adapt and invest in assets. Climateproofing adaptation measures involving hard engineering have a number of significant constraints, lacking flexibility given the long-term rate of return on investment and time taken to implement. These significantly increase potential maladaptation and opportunity costs. Few studies indicate the implications of climateproofing on performance including reducing the extent of risk, time, cost and resources required to recover. The extent to which climateproofing Kosrae's roads is actually effectual, can only be eventually proven through another risk event.

Samoa West Coast Road, Climate Resilience

Another Samoa example formed similar benefits to Pacific MSC stakeholders, investing in a climateproofing future through 23 kilometres of the main West Coast Road (World Bank 2017). The present road is highly vulnerable at sea level and three metres distance from the Pacific Ocean. Climateproofing includes asset elevation, more resilient material, expanding pavements, maintenance, design and drainage. It includes mainstreaming into climate change policy, existing legislation, augmenting stakeholder awareness, training and experience. A Vulnerability-Risk Assessment and Climate Resilient Road Strategy was designed. The project has been delayed when compared to its original schedule to 2018. It has not been tested yet by another risk event. The overall cost of climateproofing is estimated at $17,000,000 with $2,200,000 contributed by Samoa's government and $14,800,000 a World Bank loan. Unlike Kosrae, specific costs and benefits are not publicly accessible. This specific project provides similar advantages to MSC stakeholder's commercially as for Kosrae but it can be criticised as without this information, stakeholders cannot project a rate of return on investment, increasing decision uncertainty and opportunity costs.

The strategy is effective to a certain extent based on Figure 3.4 criteria as it preserves stakeholder requirements against projected risk. As the main corridor connecting supply chain economic activity, stakeholders, stages and assets, enhanced specific climate resilience of this road, indirectly lowers vulnerability/potential disruption costs of all interdependent MSC participants. It increases their capacity to evacuate and recover from risks more swiftly. It increases future adaptive capacity; given the expense of future retrofitting and replacing assets, if investments don't occur. Although no specific figures are previously researched, this report considers this strategy more effective than the alternative of inaction; in lowering time, cost and resources needed for individual stakeholders and performance to recover.

However, this Samoa adaptation project is effective only to a limited extent in reducing risk exposure. No indication has been provided to counter the existing three metre distance to the Pacific and other existing risk factors as summarised in Figures 3.2 and 3.3. As with other Pacific projects it is highly biased towards considering ocean-based risk types –cyclones, floods, storms and sea surge. The value of existing adaptation measures may be undermined by changes in soil, increased temperatures and risks of heatwaves, ocean acidification (for coral material), gales, landslides, volcanoes, earthquakes, tsunamis and fires. Uncertainty remains as to whether this measure is ecologically sustainable and flexible, given possible maladaptation cost. Myriad stakeholders remain unaware of the value and use of climate change adaptation for coastal infrastructure, ecosystem and shoreline management. They don't know how to support it or integrate it into their immediate and forthcoming business decisions. Limited private sector involvement exists, challenging the extent to which protecting core government assets can influence overall systematic risk. Loans may not be financially sustainable; representing an opportunity cost to taxpayers without any indication as to how costs will be saved or recovered.

MSC Utilities and Infrastructure Stage: Climateproofing PNG Bridge Replacement

Papua New Guinea (PNG) forms an example of how forthcoming risk management, project designs and investments can facilitate opportunities through factoring in climate change (ADB 2015). It proposed and implemented various climateproofing adaptation solutions as part of an overall strategy. Its ADB Bridge Replacement Project will adjust 20-30 bridges from a single into two lanes (from 700 nationally). It assessed various bridges for vulnerability, resilience, and adaptive capacity. These solutions included techniques to protect against scour, debris and logs, maintenance and flooding (ADB 2011). The design incorporates redundancy in capacity and provides a margin for risk tolerance. It considered how critical the asset/risk exposure was. It's designed to a 50-100 year projected lifespan for IPCC 2013 scenarios. The scenarios project a 1.1-1.6º increase by 2055 and 1.7-2.6º by 2090 plus a 10-25% increase in precipitation. This is integrated into its 2012 Strategic Programme for Climate Resilience.

The project's climateproofing adaptation cost is an estimated $100,000,000. Sinclair Knight Merz, (2012) and ADB (2015) estimate the projected rate of investment return as 15.5% over 35 years; dropping to 14% with a 10% reduction in forecast traffic. For MSC' stakeholders, the project possesses several co-benefit advantages of reduced bridge maintenance/operating costs, traffic, lower congestion, externality, safety and other opportunity costs. This includes a far less probable, conditional probability of an asset failure from a specific risk event. The extent to which climateproofing reduces risk, hasn't been currently tested for PNG's bridges. The strategy effectively answers Figure 3.4 criteria in determining whether adaptation can benefit stakeholders. Provided stakeholders are sufficiently aware of these developments, responding accordingly; core asset protection ensures resources can prioritise disruption costs, mobile assets, training, economic recovery and opportunity, during a risk event. It addresses the Precautionary Principle of environmental economics. Performance, competitiveness, productivity and total business/operation/system failure is reduced; as stakeholders are aware of infrastructure capacity and resilience standards. PNG's Bridge Replacement grants stakeholders more flexibility and adaptive capacity, then reacting under conditions of uncertainty where assets fail to preserve supply chain activity. It enables risks and impact costs to be prioritised more triumphantly.

However, PNG bridge replacement may only be partially adaptive until all stakeholders are integrated and aware. Additional research needs to consider the extent of risk reduction specifically occurring from climateproofing as opposed to cheaper, alternative methods. The measure currently ignores opportunity and maladaptation costs. Effective maintenance also needs to consider risk events to remain constructive. Core asset protection may incur risks of moral hazard. In relying upon government; stakeholders lose independent capacity to adapt and survive, given the vulnerability of their core assets. Climateproofing bridges and other infrastructure may not always be cost sensitive, ecologically sustainable or technically feasible given site-specific constraints. More research needs to consider the extent to which climateproofing adversely affects local ecosystems and environments. Effective climateproofing requires detailed, complex data, projections and information (not always certifiably available) plus the willingness of cooperative stakeholders.

Niue Integrated Water Zone Management

Niue's integrated water zone management project proposes a water utilities and private sector, adaptation solution to risk uncertainty and resource security (Buncle 2013). It reduces the impacts of specific cyclone, drought, bushfire, heatwave and temperature risk types. From 2013-2015 its output produced a local, plastic manufacturing plant, where local stakeholders have options to invest in either a 5000 or a 10,000 litre tank. Eight can be produced each day. Over 500 are manufactured for 736 people in the pilot phase. The project also targets non-climate factors including improved coastal zone monitoring, management and training via community participation for Alofi's boreholes. Local climate information will be accessible for individuals to consider if this investment is profitable. Enhanced maintenance seeks to preserve asset conditions. Climate change and water security is mainstreamed into Niue's Climate Change Policy and Joint National Action Plan for Disaster Risk Management and Climate Change (Niue Government 2012), as co-benefits.

A cost-benefit analysis verifies benefits to Pacific MSC' stakeholders in prioritising simple climate change measures. Niue possesses no groundwater, entirely dependent on freshwater harvest and storage from precipitation. Buncle (2012) and PACC (2015) estimated risk adaptation costs as NZ$5,894-$6,557 for a 5,000-litre tank and NZ$6,881-7,544 for 10,000 litres. Specific costs include the tank, gutters, fascias; pipes, device, installation and maintenance. A four percent discount rate gave costs of $6,058 and $7,006 and benefits of $6,196 and $6,256 respectively. This excludes potential benefits directly relating to risk events and opportunities; preventing a complete impartial evaluation of its effectiveness for MSC' stakeholders. It proved economical to invest, saving $138 for 5000 litres. However, a specific maladaptation cost of $750 in selecting the 10,000 litres alternative. The project is co-financed by Niue stakeholders ($96,000) and NZ$1,813,870 is contributed by GCCA, EU and PACC. $120,000 is invested in education/training, $45,000 for monitoring and evaluation and $1,590,000 to the project.

From an MSC' stakeholder perspective, this project retains several business advantages. The strategy is effective to a significant extent using Figure 3.4's evaluation criteria. Greater resource security is assured cost-effectively, so commercial activity is preserved. It augments resilience and decreases vulnerability, time, cost and resources needed to recover. This enables greater resources to be devoted to supply chain performance, quality and productivity. Buncle estimated average benefits per individual of $153 in improved water quality, $4,763 in reliability, $835 in avoided pumping and $445 in imported bottled water costs. Without adaptation, aquaculture stakeholders could not guarantee supply. Stakeholder's health and productivity are secured. The proposal is equitable, based on the user pays principle. It is ecologically sustainable with minimal externality costs. Not just across the Pacific but globally; stakeholders become increasingly dependent on undervalued, natural resources such as water. Risk uncertainty ensures these resources cannot be guaranteed. Investing in water, avoids maladaptation and opportunity cost of losing access. Desalinisation, geo-engineering and other measures are far less technically feasible, given existing constraints, as tanks and equipment may be produced locally. This indicates a simple example of how adaptation creates commercial opportunities. Greater MSC' activity, expands future adaptive capacity; over existing sources proposing risk recovery to business as usual.

However, this project is only effective to a certain extent; as it remains highly conditional upon variable precipitation. It needs to integrate across climate forecasts, information and communication so stakeholders can maximise opportunity. No indication has been provided as to where water should be provided or distributed when necessary. Effective adaptation would enable surpluses to be commercially paid for and channelled elsewhere where necessary, to alleviate scarcity in other sectors. The method faces issues raised in Chapters 3 and 6 for impact cost analysis. The project ignores core concerns such as the frequency of maintenance, the quality of training and challenges of securing sufficient spare parts. Existing water pipe corrosion increases water loss, diminishing effectiveness. It does not mention the need for integrated coastal/water resource zone management and how environment, climate and other factors affecting the extent of precipitation retention are being addressed. The project's current focus specifically concentrates only on individual households; ensuring the remaining commercial sector such as fisheries, agriculture and marine tourism remain highly insecure from disruption risks. These stakeholders remain unaware, lacking capital to adapt and other existing constraints to adaptation. Projected benefits are low. Benefits have not been assessed for the commercial implications of investing whether it can be profitable, as well as reducing costs. Projected resource demand against supply has not been estimated and connected.

MSC Insurance/Financial Sector Stage: PCARFI

Although few global examples of insurance and financial sector adaptation to climate change risks exist; the public sector has pursued PCARFI (PCARFI 2015). The Pacific Catastrophe Risk Financing Initiative concentrates on insuring public assets against risk events, aiming to decrease disruption costs. Funds are distributed after a risk event towards aid, supplies and recovery. However, the private Pacific insurance/financial sector retains limited resources, unaware, unwilling and unable to assist. This existing insurance market remains fragmented; despite covering tsunamis, cyclones and earthquakes with few staff and a low market coverage rate. The pilot scheme seeks to overcome existing private sector failure, by linking public assets with global insurance markets via the World Bank. Project output includes a database of existing assets and conditions in a Pacific Risk Information System. It includes improved risk data for all risk types utilising historical risk sources, satellite imagery, topographic maps, bathymetry, surface geology, soil, land cover and asset maps. Its outcome aims to provide stakeholders with more potent assessment tools and information. This concentrates on effective risk understanding and communication.

From a MSC' stakeholder, business viewpoint the project offers definite benefits as an effective adaptation strategy to invest in. It cost $1,170,000 for 15 Pacific nations financed by the World Bank as a loan to the SPC. Once developed, the project is economically viable as an electronic database with minimal operational costs. Greater risk awareness possibly engulfs physical, psychological and indirect costs for participants. Stakeholders are more accurately able to identify, categorise, price and prioritise risk based on existing information. Improved training and education ensures the risk is not marginalised and is factored into businesses existence and survival. In contrast to other world parts, the Pacific's investment in public sector risk awareness, catastrophe insurance and financing, ensures less adverse consequences. With finance present (even if limited) and alert, responsive stakeholders, the time, cost and resources to recover imposes less of an opportunity cost. This ensures a more effective utilisation of resources rather than reliance on external assistance, commercial sector loans and other disaster financial grants.

Protecting public assets including seaports, roads and bridges via sovereign insurance and disaster risk financing, reduces the conditional probability of an asset/system failure. This creates greater business sector certainty, as companies and individuals adjust operations to lower dependency on the most unshielded assets. Unlike Australia and the USA, stakeholders possess greater awareness of policy certainty. Insurance is mandatory and interconnects climate change risks into design standards. They are able to identify the extent to which assets are protected with greater risk awareness from the existence of an electronic and centralised inventory of assets. The public sector frequently has greater access to information, resources, legislation and enforcement capacity to allocate post-event resources, design sufficient asset coverage to risks. PCARFI is more technically feasible for the public than private sector resources needed to replicate data and funding. Insurance and funding retains future functionality of supply chains with greater flexibility as funds are swiftly dispersed after an event (unlike Hurricane Katrina). It assists supply chains to recover more swiftly. Core asset protection, a central asset register and a disaster budget provide a pre-emptive rather than uncoordinated and reactive approach to climate change risk management for MSC's. This is based on the precautionary principle. Given public sector, externality costs, it ensures taxpayers finance public good insurance.

However, PCARFI in its current form remains ineffective as a climateproofing adaptation strategy for MSC' stakeholders. The fundamental challenge is its inaccessibility for neither this researcher, communities or individuals are able to access its risk information or asset register data base. There is no indication or provision of time series data upon which to produce the risk information nor any adequate detail as to how its forecast probabilities are calculated. Its methodology ignores factors affecting risk, conditional probability of an asset failure and impact cost. It lacks actual case studies assessing performance (in contrast to Chapters 5-7) and criteria assessing the degree to which it remains effective. Only limited funding exists. It may not be commercially viable without individual and private sector involvement and sponsorship. Limited resources and coverage exist as it does not resolve existing stakeholder constraints to adaptation. No incentive exists to reduce risk for individuals or the private sector. Psychologically it does not counter issues of asymmetrical information and moral hazard –investing in physical risk protection may facilitate greater individual risk behaviour. Public sector insurance violates the equity or user pays principle for private goods. Certain core assets are only partially or not protected. For limited funding, no indication exists as to how funds can be accessed. No indication is provided as to which risks should be prioritised, where to prioritise and why. PCARFI remains only applied to the public sector. MSC' private sector stakeholders remain highly vulnerable to disruption as detailed in Chapter 5 and Table XI(a).

Appendix XIII: Key Cook Islands, MSC' Stakeholder Directory.

- 88FM
- ACE Insurance Limited
- Airport Authority
- Aitutaki Fishing Club
- Aitutaki Village Council
- Allied International Insurance Limited
- ANZ Bank
- Aquila Transport
- Atiu Fishing Club
- Bank of Cook Islands
- Bank of South Pacific
- Baxter's Water World (Fish Exporters and Processors)
- Bergman & Sons
- Black Pearl Jewellery.
- Bluesky Cook Islands (Telecommunications)
- Business Trade Investment Board
- CITC Supermarket
- Climate Change Cook Islands
- Cook Island Aquafarm
- Cook Islands Civil Society Organisations Inc
- Cook Islands Customs Authority
- Cook Islands Fishing Associations
- Cook Islands Game Fishing Club
- Cook Islands General Transport
- Cook Islands Investment Corporation
- Cook Islands Meteorological Service
- Cook Island News
- Cook Islands Noni Marketing Limited
- Cook Islands Pearl Authority
- Cook Islands Port Authority
- Cook Islands Tourism Corporation
- Cook Islands Towage Limited
- Cook Islands Trading Company
- Cook Islands Trust Corporation Limited
- Cruise Cook Islands
- Elijah Communications –Radio Cook Islands/Cook Islands TV
- Emergency Management Cook Islands
- Excil Shipping
- Fairlady Pearls
- Federal Pacific Insurance Limited

- Financial Supervisory Commission
- Foodland
- Goldmine Jewellery and Gifts
- Hawaii Pacific Maritime
- HPM De-vanning Stevedores
- Infrastructure Cook Islands –WATSAN Unit
- Island Craft Ltd
- Kai Moana (Fish Exporters and Processors)
- Luen Thai Fishing Venture
- Mangaia Fishing Club
- Mangaia Island Administration
- Manihiki Black Pearls
- Maritime Cook Islands (MCI)
- Matina Travel Limited Shipping Agent
- Matson Rarotonga Shipping Agents
- Mervin Communications Limited (Radio)
- Ministry of Agriculture
- Ministry of Finance and Economic Management
- Ministry of Infrastructure and Planning
- Ministry of Marine Resources –Fisheries, Inshore Fisheries Management and Aquaculture
- Ministry of Transport
- Mitiaro Fishing Club
- Muri Care Group
- National Council of Women
- National Environmental Service Integrated Islands Biodiversity/Invasive Alien Species Project, --Ridge to Reef, Islands Future, Education
- NPDRMCC –National Platform for Disaster Risk Management Coordinating Committee.
- National Sustainable Development Commission
- Office of Statistics
- Ora Moana Limited
- Pacific Energy
- Pacific Forum Line Shipping
- Pacific Schooners Limited
- Paka's Pearls
- Pitt Media Group –Cook Islands Herald
- Prime Foods Limited
- Prime Minister's Office
- Raina Trading
- Rarotonga Black Pearls
- Rarotonga Freight Services
- Reef Shipping
- Seabed Mineral Authority
- Sovereign Assurance Company Limited

- Taio Shipping
- Teanaroa Paka Worthington (Pearls)
- Te Aponga Uira (Electricity)
- Telecoms Cook Islands
- The Convenience Store
- Toa Petroleum
- Tower Insurance (Cook Islands) Limited
- Transam Cook Islands Shipping
- Triad Pacific Petroleum
- Tyrone Pearls
- Uma Shipping Limited
- Willis New Zealand Limited Brokers
- Wigmore's Super Store